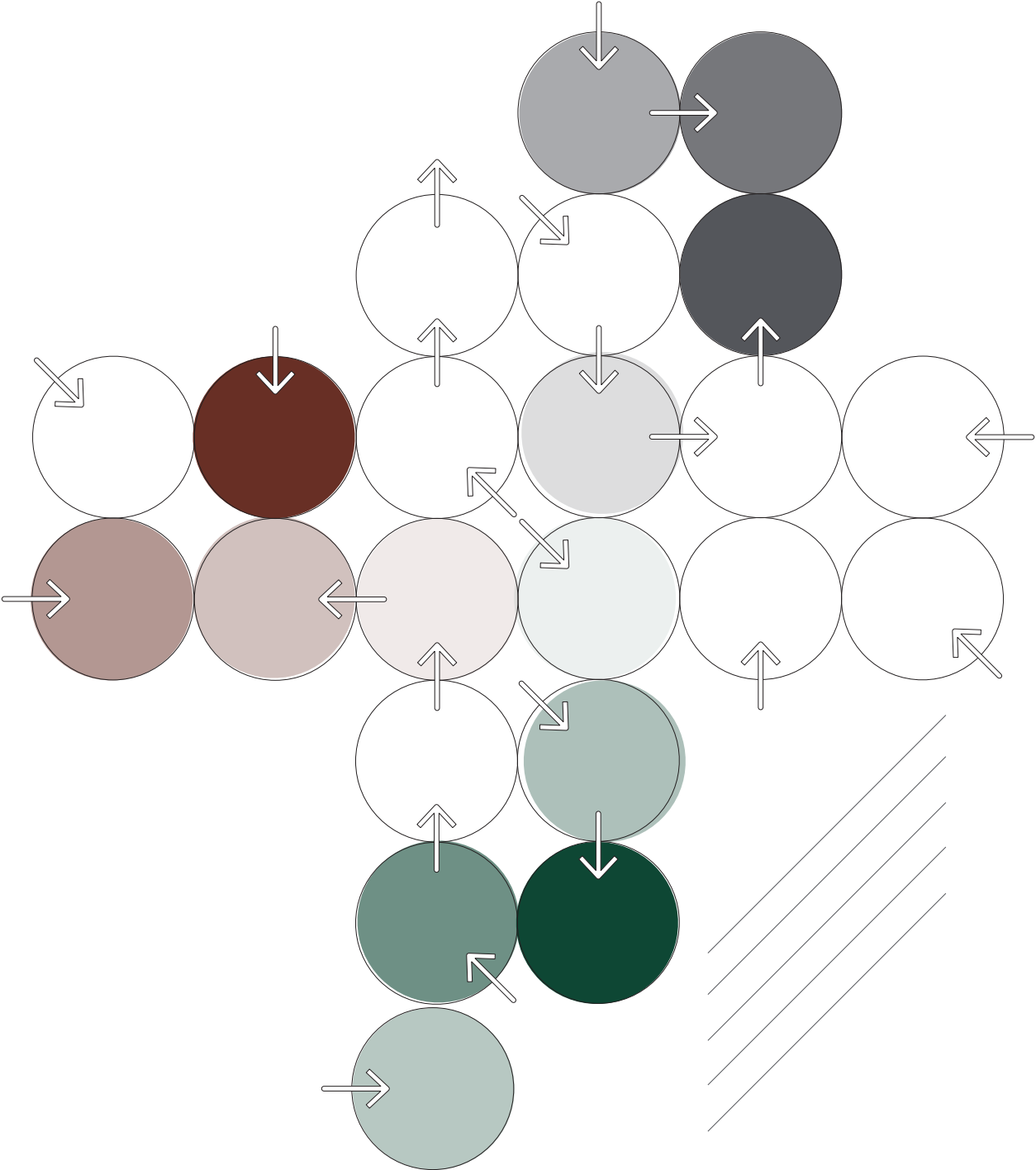


Carbon Narratives

for Design Planning



Carbon Narratives for Design Planning

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Mark Fretz is Assistant Professor of Architecture in the Department of Architecture at the University of Oregon and is Interim Co-Director of the Institute for Health in the Built Environment. Mark is PI for this project and has contributed to all project phases, including proposal, literature review, survey instrument design and administration, organization of workshops, writing and editing of the field guide and overall project management.

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The Narratives

The carbon story for buildings exemplifies the complexity and interconnection of embodied and operational carbon contributing to global greenhouse gas (GHG) emissions causing climate change. A myriad of considerations are in play, from natural resource management, extraction, processing, transportation, construction, operation and ultimately end of life, for every material and every building. Buildings currently represent about 37% of annual global CO₂ emissions.¹ About 10 GtCO₂ annually come from building operations, which is at an all-time high, and about 3.6 GtCO₂ from producing major materials used in building construction.¹ As the world economy grows and living standards rise, the global consumption of raw materials is expected to nearly double by 2060.¹

Decarbonizing the building sector will require coordinated action from numerous and diverse stakeholders in areas such as science, policy, and finance. Architects, engineers, and construction (AEC) professionals can take greater responsibility through building material selection, but this important decision-making process requires having the right data at hand when it's needed.

We believe the quickest means to reducing global warming potential through building material selection in the near term is to: 1) use and reuse materials efficiently, including existing structures; 2) use low embodied-carbon material options in place of materials that are derived from carbon intensive production; 3) employ bio-based materials, such as timber, that are renewable and remove carbon from the atmosphere during their growth, then design for durability and longevity, disassembly, and end-of-life reuse to ensure that the stored carbon remains out of the atmosphere for as long as possible; 4) create opportunities to use mill and production waste in products with long lifespans. At present, timber is typically less carbon intensive than steel or concrete if sourced from forests with sustainable forest management practices.

On a longer time horizon, we believe: 1) significant reductions in all industry emissions and continued improvements in sequestration are imperative for all building materials including wood, concrete and steel; 2) transitioning a significant percentage of our buildings and cities to timber structures could significantly reduce carbon emissions

in time, but only if sustainable forest management practices are used in concert with strong forward-thinking governance and broad-reach planning efforts; 3) sustainable forestry practices, along with the life cycle assessment methodologies and design tools used to quantify their impacts, are still in a period of development and refinement, and should be expected to be a moving target in the foreseeable future with advancement in our collective understanding and through greater adoption of these systems and practices.

This guide, *Carbon Narratives for Design Planning*, was developed to acknowledge areas of influence when considering selection of mass timber as a primary building material. It is a complicated narrative, but one that designers and their clients are embracing based on multiple positive attributes of mass timber. At the same time, there is consensus that more transparency and uniformity in the embodied carbon story of wood products from forest to building site will lead to more informed decisions and improved environmental outcomes when specifying materials during design planning.

This project offers a synthesis of available information for primary materials of structural building systems, with particular focus given to mass timber. We highlight ways in which mass timber can reduce whole building embodied carbon yet recognize that the narratives become complicated when comparing carbon content in mass timber structural systems against concrete or steel. The narrative becomes further nuanced when forest management practices, biogenic carbon and unknown material end-of-life pathways become part of the equation.

The guide is structured in five parts, describing: 1) carbon in the built environment; 2) carbon, climate and forests; 3) carbon and mass timber; 4) carbon and concrete and

5) carbon and steel. Additional resources included in the appendices are survey results from 180 AEC practitioners from across North America, many with international project experience, that were used to structure a series of five workshops that took place between April and September 2021: 1) Wood Certifications: What is the difference and is it worth the extra cost? 2) Beyond the EPD: What aren't we considering? 3) Comparing Carbon Narratives: How do concrete, steel and mass timber actually perform? 4) LCA Assumptions: Counting carbon neutrality versus climate neutrality? 5) Design for Building End of Life: Assumptions versus Actualities. Workshops drew on expertise and perspectives from individuals in forest ownership and production at small and large scales, manufacturers, non-profits, government and academia. Due to the Covid-19 pandemic, these workshops were held entirely virtual, which allowed participation of national and international experts. Links to workshop recordings are hosted on the Institute for Health in the Built Environment (IHBE) and NetZed Laboratory websites.

The immediate goal of this work is to create a common narrative for use by AEC professionals in their current and future work involving specification of building materials and associated carbon impact from those choices. Longer range goals of this work are based on the belief that these carbon narratives are key to advancing research, innovation, and cross-disciplinary urgency surrounding broad efforts to decarbonize the building sector and the materials used in the built environment.

¹2022 Global Status Report for Buildings and Construction, UN Environment Programme, <https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction>

An aerial photograph of a city grid, likely New York City, showing a dense network of streets and a prominent river (the Hudson River) winding through the urban landscape. The image is dark and serves as a background for the text.

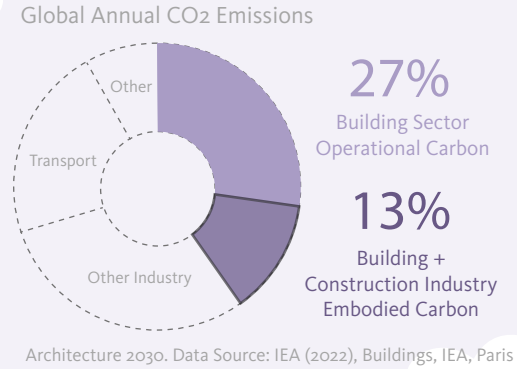
CARBON THE BUILT ENVIRONMENT

Key Points from the *Carbon Narratives for Design Planning Project*

1. The global building stock is increasing rapidly and expected to double in current floor area by 2060. Buildings account for approximately 40% of global annual CO₂ emissions, and therefore have a significant role in climate change.
2. Embodied carbon resulting from building material selection is important to consider now because those material emissions occur when a building is constructed and cannot be reduced over time. Thus, they become “locked” into today’s building projects.
3. Building structural systems are the largest source of embodied carbon in a building (up to 80%); therefore, initially focusing on structural material has the biggest embodied carbon impact. Bio-based materials offer a potential solution to mitigate embodied carbon emissions associated with construction of the built environment.
4. The quickest means to reduce global warming potential (GWP) at the material level is to use material efficiently; therefore, less of it. Reuse existing structures and materials, then substitute carbon intensive materials derived with fossil fuels with low-carbon materials. Although the substitution benefit of timber is difficult to determine, it is still generally less-carbon intensive than steel or concrete.
5. The long term climate benefit of timber products improves the longer biogenic carbon is stored away from the atmosphere. This means that designers should focus on design for durability, longevity, disassembly and material end-of-life reuse to improve the carbon story. Furthermore, designers should select products that convert and use biogenic mill waste into long-term architectural materials.
6. Letting trees mature without harvest would only create a one-time benefit as carbon sequestration will ultimately reach a limit. Harvesting trees and replanting before rates of carbon sequestration decline allows for continual carbon sequestration over time, with carbon stored in wood products shifted to the built environment after each harvest.
7. For new construction, transitioning to timber cities (particularly for mid-rise projects) can have a significant reduction in carbon emissions by 2100. A recent study by Mishra, et al., (2022)³³ found that if 90% of the population lived in timber cities, this could realize a 77% reduction in atmospheric carbon over business as usual if wood products were from sustainable forest management (SFM) with strong governance and careful planning to protect frontier forests and biodiversity hotspots.
8. Carbon neutrality is different than climate neutrality due to the timescale. Carbon neutrality under steady-state forestry is an oversimplification of reality and discounts the complexity of emissions and sequestration. Being “carbon neutral” does not mean that we will necessarily meet climate goals (“climate neutral”) because emissions occurring now do not have enough time to be offset.
9. LCA methodology and assumptions are critical when assessing biogenic carbon life cycle emissions. Although more complex, dynamic LCAs offer a more comprehensive, understanding of carbon fluxes; however, design tools will need additional development.
10. For all three typical structural building materials, wood, concrete and steel, efficient and judicious use of material is important to reducing embodied carbon.

Embodied Carbon vs. Operational Carbon

In order to avoid significant repercussions from the impacts of climate change, the Paris Climate Agreement warns that the average global temperature must not increase by more than 2°C (preferably 1.5°C) relative to pre-industrial temperature levels.¹ As anthropogenic activity continues to be a source of CO₂ emissions, it is pertinent to reduce our carbon footprint. The built environment accounts for about 40% of global greenhouse gas emissions.²



There are two types of carbon emissions.

Operational Carbon

CO₂ emissions that are a result of energy consumption to support building functions such as lighting, ventilation, heating and cooling.

Embodied Carbon

All CO₂ process emissions that are a result of material extraction, manufacture, transportation, construction, maintenance, and disposal.

Why is embodied carbon important?

By the time construction materials reach the project site, embodied carbon is already in the atmosphere.

Operational carbon currently makes up the majority of building sector emissions. Luckily, these emissions can be reduced over time through efficient design and use of renewables. Embodied carbon on the other hand, cannot be mitigated throughout the service life of a building as these emissions are upfront and locked.³ For new buildings, embodied carbon emissions typically are equivalent to approximately 20 years of operating emissions.³

Addressing embodied carbon is urgent.

The world's building floor area is expected to double by 2060 (an additional 2.4 trillion SF), which is equivalent of adding a New York City to the planet every month for the next 40 years.²

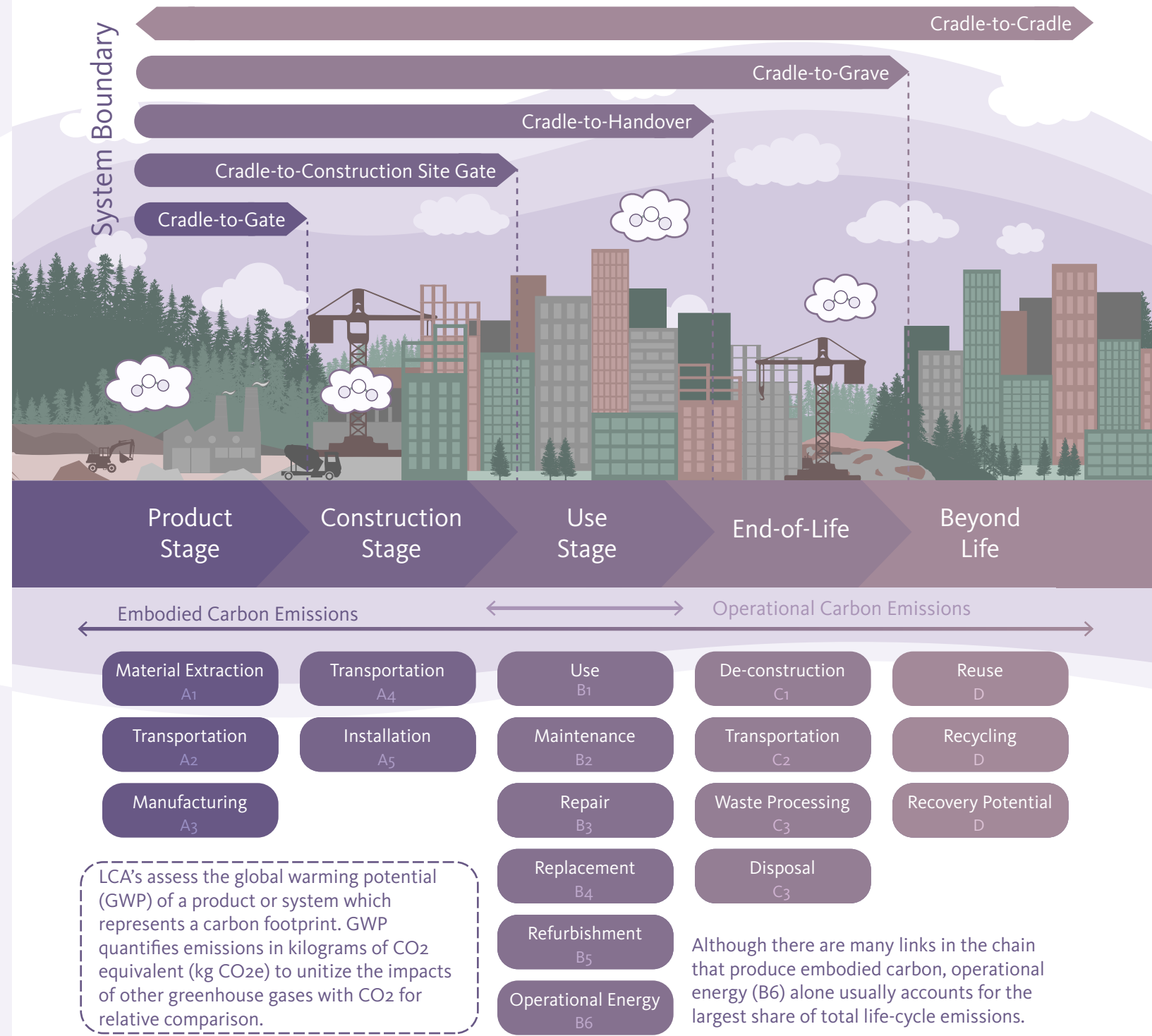
A growing building stock requires embodied carbon to be addressed now in order to meet future climate change mitigation targets. As building operation efficiencies increase, embodied carbon will become a more substantial share of building sector emissions.^{4,5}

LCA: An Important Climate Tool

How do we quantify and assess carbon emissions?

Life cycle Assessment (LCA) is a method for the collection and evaluation of the inputs, outputs, and the estimated environmental impacts of a product or system in its life cycle.

A LCA can be carried out at the scale of a single product or a whole building, often called a Whole Building Life Cycle Assessment (WBLCA). A suite of international ISO standards provides an overarching framework for this method, from which national and third-party programs derive more specialized guidelines. LCA studies may consider only a portion of the entire life cycle, which is defined as the project's system boundary.

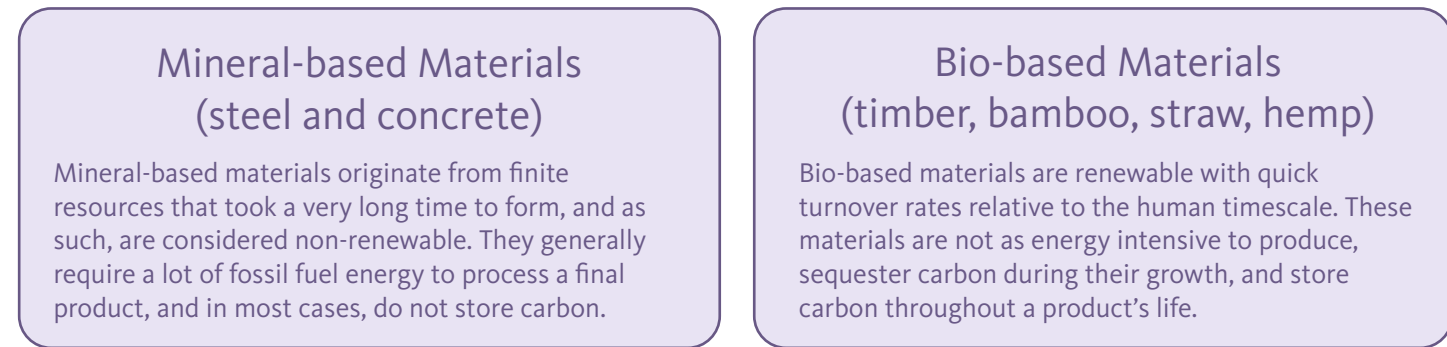


Mineral-Based Materials vs. Bio-Based Materials



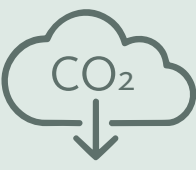


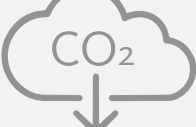



Structural systems typically are the largest source of embodied carbon within a building, up to 80% depending on building type.³ Different systems have different associated impacts that can vary based on factors such

as sourcing, manufacturing process, recycling and end-of-life assumptions. The main structural materials used in constructing primary load resisting systems today are steel, concrete and timber.

Materials are typically either mineral-based or bio-based, with characteristics that make them high-impact or low-impact materials (aka climate-smart materials).



A quick look at timber, concrete and steel shows that bio-based construction materials offer one potential climate change mitigation strategy to reduce building sector emissions.

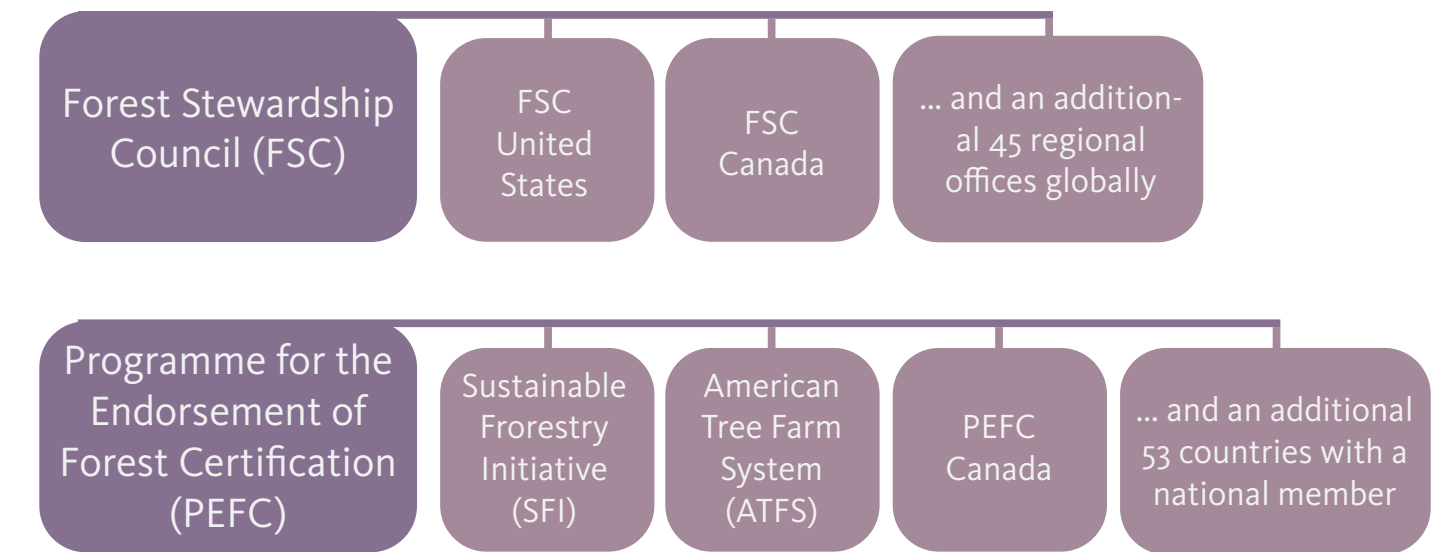
	Is it renewable?	Is it energy-intensive?	Does it store carbon?
TIMBER	Trees are renewable if soil nutrients are carefully managed 	Comparatively less energy is needed to manufacture timber products 	Trees sequester carbon through photosynthesis 
CONCRETE	Limestone, clay, sand and other aggregates are finite resources 	Lots of energy is needed to fuel kilns for clinker production in manufacturing cement, the glue in concrete 	Concrete sequesters carbon through carbonation 
STEEL	Iron ore is a finite resource 	Lots of energy is needed to extract and process ore and fuel furnaces for steel-making 	Steel does not store carbon 

Forest Certifications

To realize the environmental benefits of timber as a building material, timber must be produced and sourced from forests employing sustainable forest management (SFM) practices. Since most timber is sold on commodity markets, forest certifications have become a mechanism to provide third-party oversight of managed forests and signal

to consumers that their purchase complies with a set of standards, criteria, and indicators of performance to meet that system's ecological, economic, and social performance goals. They not only attempt to influence consumer and market behavior in supporting these goals, but also allow consumers to do so by purchasing certified products.⁶

Forest Certification Program Relationships⁷



Two major schemes have taken prominence globally, the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC).

Forest certifications have demonstrated a level of success as seen by positive growth trends over the last two decades.⁷ Furthermore, certification has been suggested to encourage improvement beyond legal compliance and induce substantial positive change to large-scale forestry businesses.¹³ Yet, it is difficult to distill a general or global conclusion on the effectiveness of forest certifications for a number of reasons including: differing forest biomes, varying regulations and governance in different regions and countries, varying harvest methods, inadequate consideration of temporal and spatial dimensions with respect to forest ecosystems, as well as different study designs and methods applied.^{16,17} Lack of reliable empirical data, the constant evolution of certification systems and their criteria, and narrow scope of investigations further complicate their assessment and specific comparison.⁶

Patterns drawn from existing FSC and PEFC forests, however, show an overall positive environmental impact

compared to non-certified conventional forestry.¹⁷ Certification has substantial environmental benefits at the cost of reduced short-term financial profitability,¹⁶ although the effectiveness and economic viability of forest certification develop over time as measurable impacts emerge.¹⁰ It should be acknowledged that trade-offs exist within forest management, meaning the goal of SFM will likely be unattainable for all variables and at all scales.¹⁶ Furthermore, forest managers often pursue different goals (e.g., profit, biodiversity) which may prioritize one ecosystem service over another. Aside from the obvious need to avoid forest degradation, the success of forest certifications will depend on the minimization of trade-offs while retaining profitability.

The reader is directed to *Carbon Narratives for Design Planning* workshops 1 and 2 for additional in-depth discussion of forest certifications from the perspective of small- and large-scale land owner, manufacturer, academic, governmental and non-profit stakeholders.

Substitution Benefits

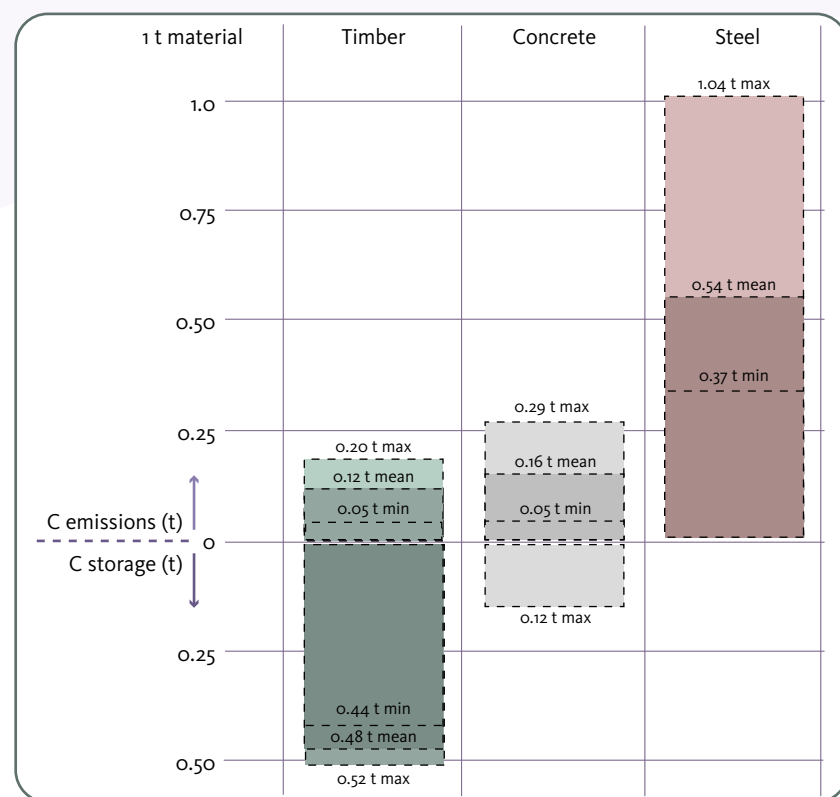
Substitution benefits are the life cycle emissions avoided by choosing bio-based materials over mineral-based materials.

Replacing steel and concrete with timber, allows for quick emission savings, despite benefits from carbon storage.⁴



Substitution benefits might have a greater impact on climate change mitigation compared to carbon storage, but are difficult to determine.^{18,19}

Carbon Emissions and Storage Capacity for 1 metric ton of timber, concrete and steel²⁰



A metric ton of wood is not a direct swap for a metric ton of steel or concrete in a building. Some level of design of primary structural systems are regularly applied early along with current market pricing to decide, based on cost, what material to use. Extending the selection criteria to carbon would be done in a similar fashion, knowing something about the design of the system, and knowing how much (mass/volume) of each material will be used. A carbon efficient system is often a cost efficient one.

Some researchers believe substitution benefits are overstated and rather limited in contributing to climate mitigation, especially when looking into the future, as studies often treat displacement values as permanent even though energy grids and other industries have time to decarbonize,^{21,22} but this same progress can be said for the wood industry. Furthermore, it is challenging for the concrete and steel industries to decarbonize completely as these industries are faced with technical and economic barriers. For example, 60% of the carbon emissions from cement production come from lime production which is a natural chemical reaction. The remaining 40% of the carbon emissions are from energy use. It is argued that modern kilns have reached thermodynamic efficiencies with little room for improvement. The steel industry, on the other hand, continues to use coke and petcoke to reduce iron oxide. Ultimately, any reduced benefit would not be realized for some time and has negligible impact on immediate estimates for emissions avoided during material production (A1-A5) which is the critical period for substitution.²³

The substitution benefit of timber is difficult to determine given the wide range of displacement factors found in various studies. A wide range of factors exists because there exists a wide range of materials, different contexts by which those materials are used, and different scopes of LCA assessment.²⁴ However, one largely referenced meta-analysis found that for every tonne of timber used, 3.9 tonnes of emissions are avoided.²⁵ Regardless, results from numerous LCAs show that timber will avoid emissions.

Carbon Storage Benefits

Forests cover a third of the planet,²⁶ and are responsible for absorbing up to a third of emissions.²⁷ How to best manage forests in the context of climate change mitigation remains a highly controversial issue with two general perspectives for the role of forests.

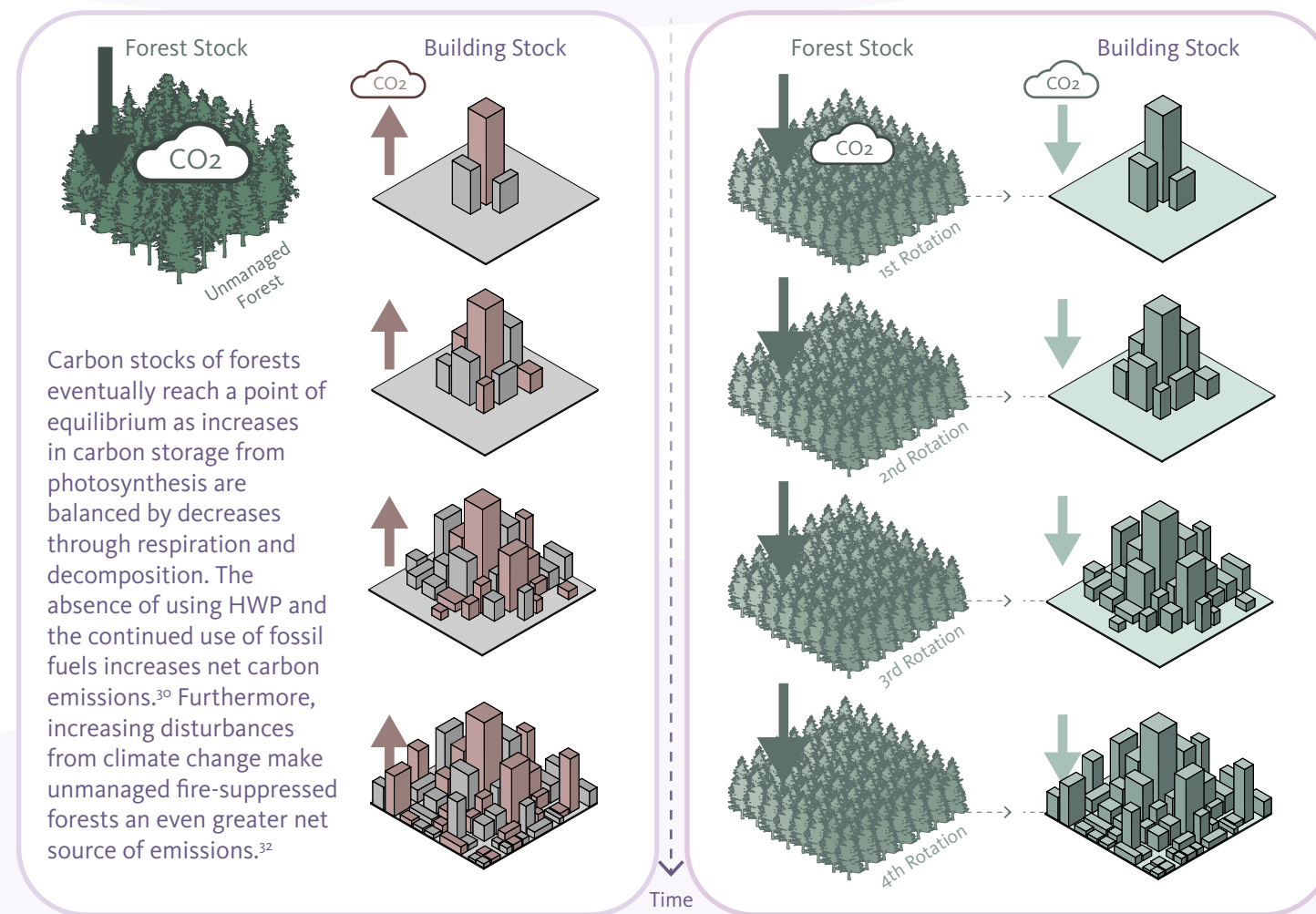
Maximizing Forest Carbon

Opponents to increasing harvest argue that forests can store carbon for many hundreds of years unlike short rotation forestry or buildings which temporarily store carbon throughout their service life.²⁸ While some emphasize leaving forests alone, reducing harvest does not provide wood products. An adaptable approach suggests that forests can become more effective carbon sinks through improved forest management and efficient, durable wood products usage.²⁹

Maximizing Urban Carbon

Proponents of harvested wood products (HWP) argue that the greatest source for carbon mitigation comes from displacing fossil fuels and that maximizing forest carbon storage is a one-time creation of a carbon sink; therefore, does not continue to reduce carbon emissions made possible by tree growth, harvest and active reforestation.^{30,31} It is even suggested that the carbon storage density of mass timber cities may be comparable to, or even greater than, the most carbon dense forests in the world.²⁰

Harvest can be beneficial to long-term carbon storage.



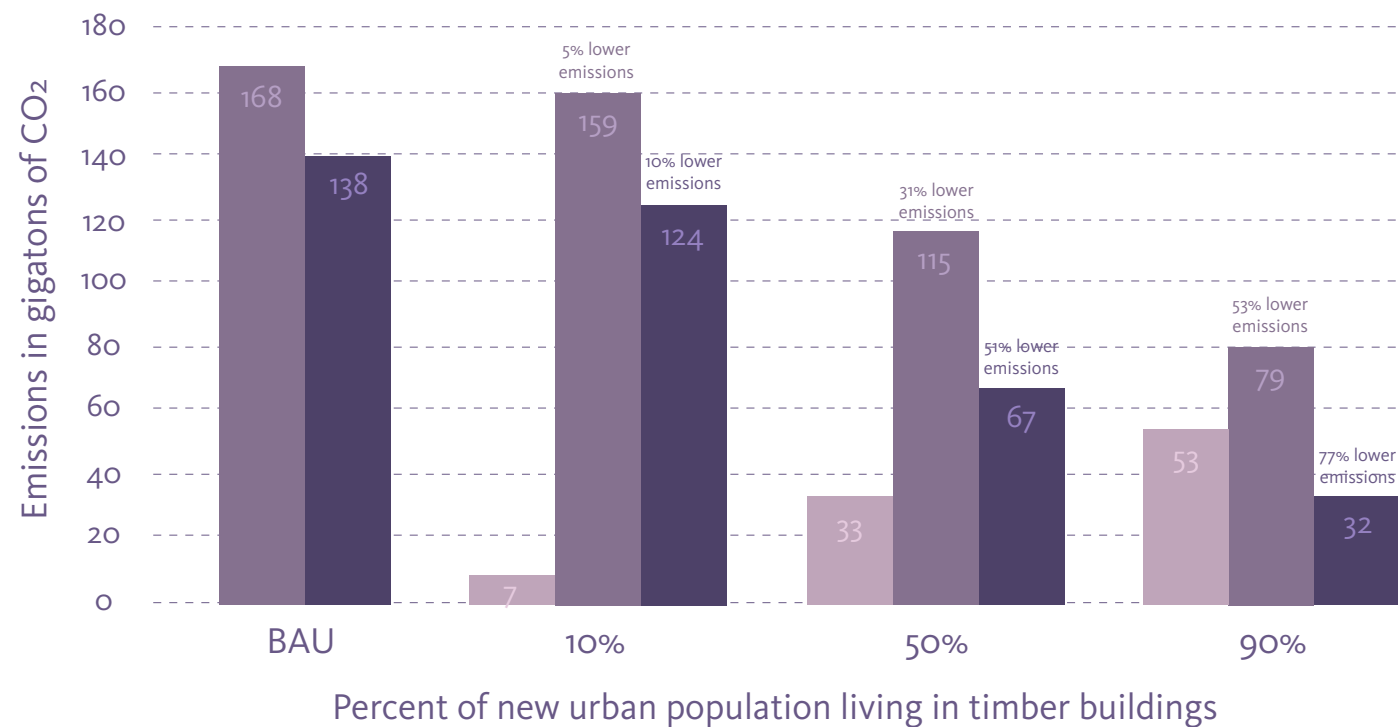
Increasing the lifespan of a building alongside forest regrowth will increase carbon storage potential. If building life is shorter than the rotation, but the carbon stored in the forest is stable or increasing then the benefit is driven by the degree to which there is a substitution benefit, and the ultimate fate of the wood. If carbon is stored in buildings longer than the average harvest rotation, then both sources should be considered a carbon sink.²³

Building Timber Cities

Ambitious demand of engineered wood products (EWP) provided by sustainable forest management (SFM) for transitioning to timber cities leads to greater emissions savings compared to scenarios where no timber buildings are constructed to meet future urban development.³³ However, it is estimated that global demand from 2020-2050 will exceed the current capacity of global forests,

providing only 36% of timber supply assuming no trade between nations. More detailed supply side analysis is needed to prevent illegal and unsustainable harvests in the developing world.³⁴ Therefore, increasing timber demand would require an increased establishment of plantations or improved forest management.^{33, 54, 55}

Transition to timber cities, emissions by 2100³³



Net emissions from construction and usage of new timber buildings by 2100
Long-term carbon storage potential of EWPs is many times higher than timber embodied carbon emissions.

Cumulative land-use change emissions by 2100
Land-based emissions savings are driven by forest regrowth in natural forests and in plantations following active reforestation, alongside long-term carbon storage in buildings.

Overall emissions by 2100
Reduced overall emissions are a result of lower net land-related emissions and emissions avoided by substituting mineral-based materials

Emissions savings for increased timber demand and construction of mid-rise buildings by the end of the century are shown. BAU (“business as usual”) assumes no timber buildings are constructed for new urban dwellers; 10%

assumes 10% of new urban population living in timber buildings; 50% assumes 50% of the new urban population is living in timber buildings; and 90% assumes 90% of new urban dwellers are living in timber buildings.

Land-Use Change

The biggest threat to forests ... is deforestation and land-use change. It is important to ensure that forests remain forests through reforestation management, and restoration.

Producing timber for buildings results in higher forest regrowth over time... due to the establishment of new forest plantations on otherwise less productive land as well as reduced share of production from natural vegetation, resulting in net carbon uptake rather than release. Highly productive plantations can help to meet this demand and alleviate pressure on natural forests protected by strict regulations.³³

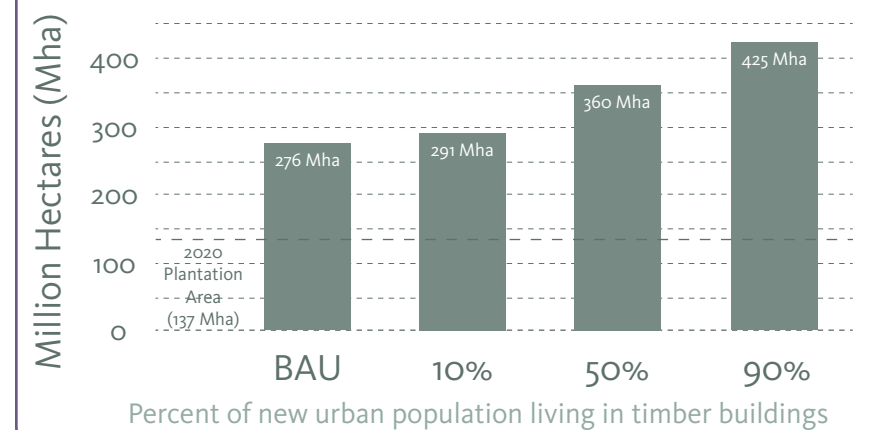
Higher establishment of plantations... will convert acreage from unprotected natural forests and other naturally vegetated land possibly resulting in a decline of biodiversity.^{33, 55}

On the flip side... More and better-managed forest lands and more efficient product uses provide significant opportunities to reduce CO2 emissions, especially in highly productive forest regions.³¹

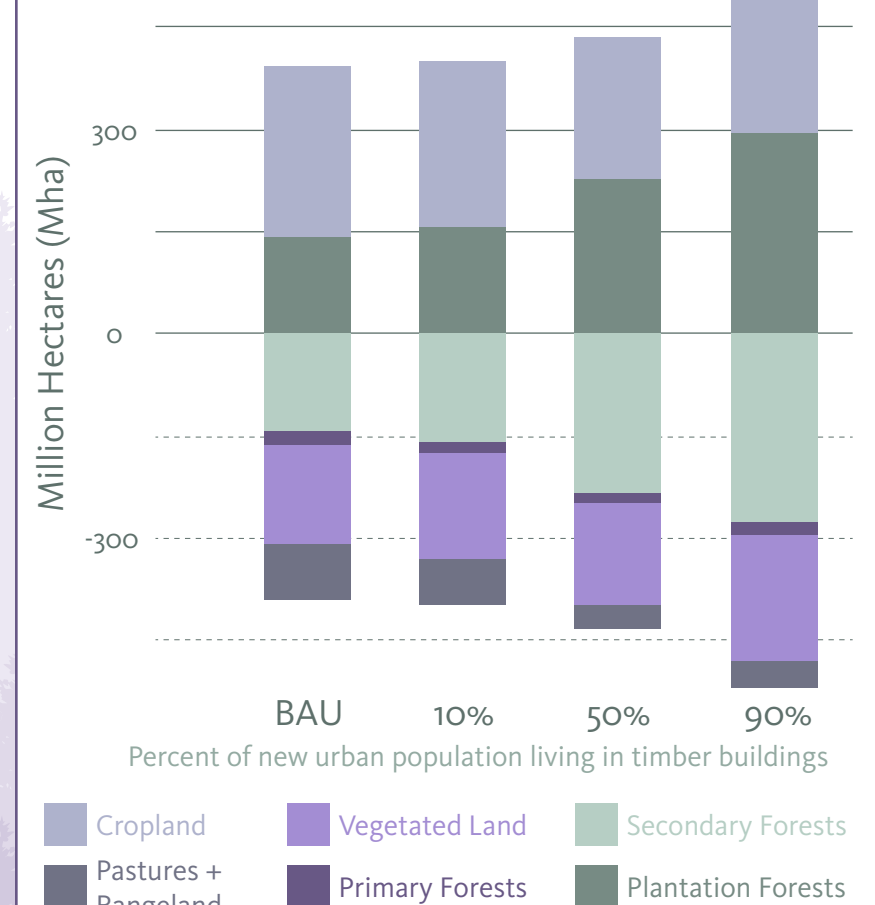
Planting more trees increases opportunity of what we want from forests... including carbon stored in more forests, more supply for timber products, and greater opportunity to set aside forests for biodiversity and habitat.³¹

Timber might not be the “one-size-fits-all” solution... a rigorous and well-designed approach to sustainably managing forests with efficient utilization of wood products can maintain or increase global stored carbon in forests and buildings but the accounting is complex. For some regions, timber solutions might not be possible or desirable, particularly where governance structures will have difficulty ensuring a sustainable timber economy.³⁴ Judicious selection and use of materials is important for reducing embodied carbon.

Projected Global Forest Plantation Area by 2100³³

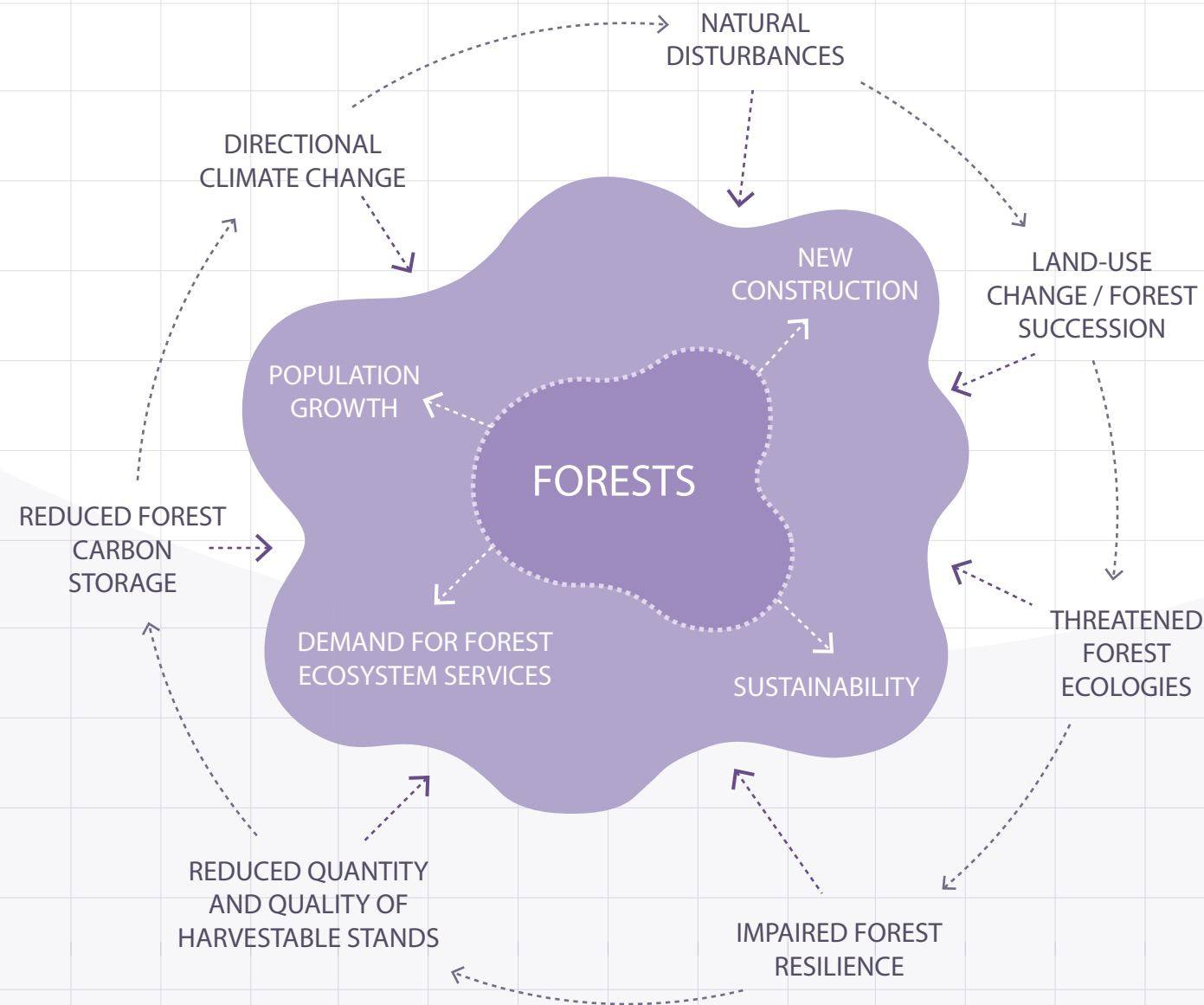


Projected Land-Use Change by 2100³³



Positive numbers represent an expansion of that particular land-use area while negative numbers represent a reduction. The sum of positive and negative changes is always zero as the expansion of a particular land-use is at the cost of another land-use type.

Efficiency With A Valuable Resource: Forests



Directional climate change imposes a number of environmental pressures which threaten the future availability of forests and their ability to store carbon. As demand for timber products, and ultimately forests, is projected to increase to meet new construction, it is important to be cautious and efficient with wood fiber consumption. Declines in wood supply will have implications for the availability of sustainably harvested wood products while declines in forest area and resilience will have even broader ecological consequences. The AEC industry is a large driver of the forest products market which invariably affects forest management and ultimately forest dynamics. Designers looking to reduce their carbon footprint should be aware of their influence over wood consumption since designing wood buildings inherently means designing forests themselves. Wood product consumers are encouraged to work with forest managers to develop context-appropriate supply chain relations that enhance ecological, social, and economic benefits. Product innovation that maximizes wood fiber efficiency coupled with thoughtful design and integration of such technologies in architectural applications can further take advantage of efficient wood consumption.

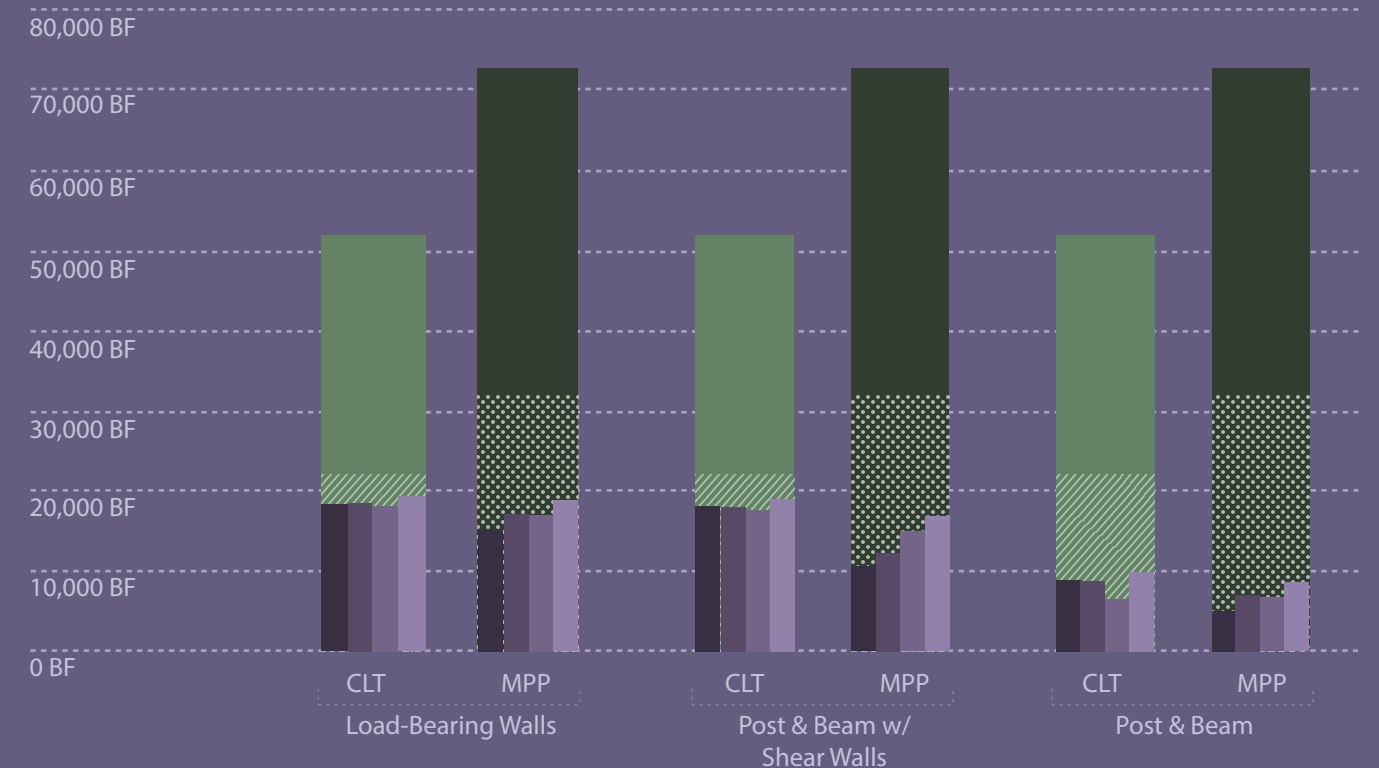
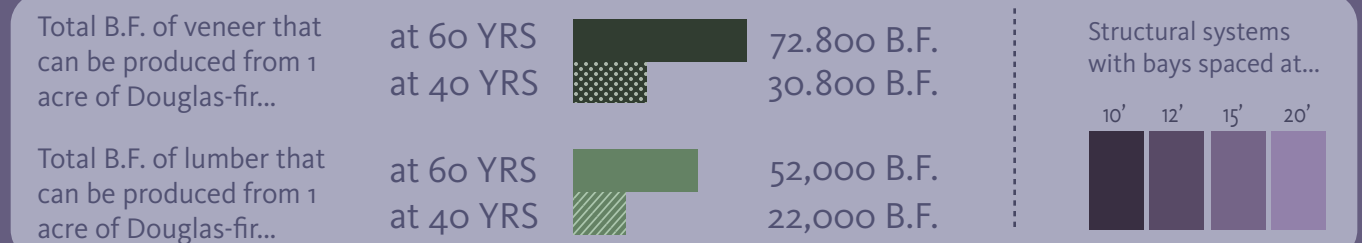
Case Study: Wood Yield and Usage Efficiency

Using the McDonald-Dunn Research Forest located at Oregon State University in Corvallis, Oregon as a case study, two even-aged stands of Douglas-fir classified with stand productivity at site index three were investigated to determine the difference in wood yield when stands were harvested at 40 vs 60 year rotations. Stands of Douglas-fir were chosen because this predominant species is commercially grown in the PNW region and is highly sought after for manufacturing wood products. 40 and 60 year rotations were chosen because the former is representative of commercial forestry, and the latter more sensitive to increasing ecological benefits. Results show that extending rotations an extra 20 years increases wood yield by approximately 136%.

Wood fiber efficiency was also studied in terms of savings in wood volume when utilizing veneer-based timber products compared to lumber-based timber products, particularly mass plywood panels (MPP)

and cross-laminated timber (CLT) respectively. MPP not only utilized roughly 20% more roundwood than CLT, but requires about 20% less wood fiber to achieve comparable structural loads.

The chart below shows wood consumption for the preliminary design of a hypothetical 27,000 cb.ft. "box" building constructed out of both CLT/glulam and mass plywood products relative to wood sourced from both one acre of Douglas-fir harvested at both 40 and 60 yrs. To reflect wood savings as a result of design choices regarding structural optimization, three approaches were used to design the conceptual building's primary structural system, with each approach incorporating four different spans between bays. Results show that at the building scale, scenarios utilizing MPP on average used ~ 20% less wood fiber in terms of total building wood volume. In terms of log utilization at the stand level, scenarios utilizing MPP harvested ~ 40% less trees from a given stand of Douglas-fir.



Carbon Neutrality vs. Climate Neutrality

If we consider bio-based construction in cities as a legitimate carbon pool, then comprehensive LCA methodologies must be employed to assess the cumulative effects of carbon sequestered, stored, and emitted in biological systems, such as trees, known as “biogenic carbon”.²² There is no consensus on how to precisely assess biogenic carbon in LCA, yet the choice in accounting method is important because it can lead to very different conclusions.^{18,19,34}

Traditional LCAs typically reduce the climate impacts of greenhouse gases to a single metric, usually GWP100 for buildings, as is calculated in methods published by the

IPCC. GWP100 represents the cumulative warming effects of greenhouse gases over 100 years relative to the warming effect of carbon dioxide (kgCO_{2e}).^{18,24} Although GWP100 has become general practice, it may be insufficient to properly assess warming impacts since forest growth and building life take place over long time spans and therefore may not fully capture all relevant climate impacts.⁴⁹ A general distinction between permanent and temporary biogenic carbon storage is whether biogenic carbon is stored for more or less than 100 years, respectively.⁵⁰ The conservative approach is to assume that biogenic carbon is stored only temporarily with no credit given for temporary carbon storage.²⁴

Two approaches to assessing biogenic carbon:

‘-1/+1’ approach

The ‘-1/+1’ approach tracks all biogenic carbon flows, where (-1) uptake and (+1) release is considered.

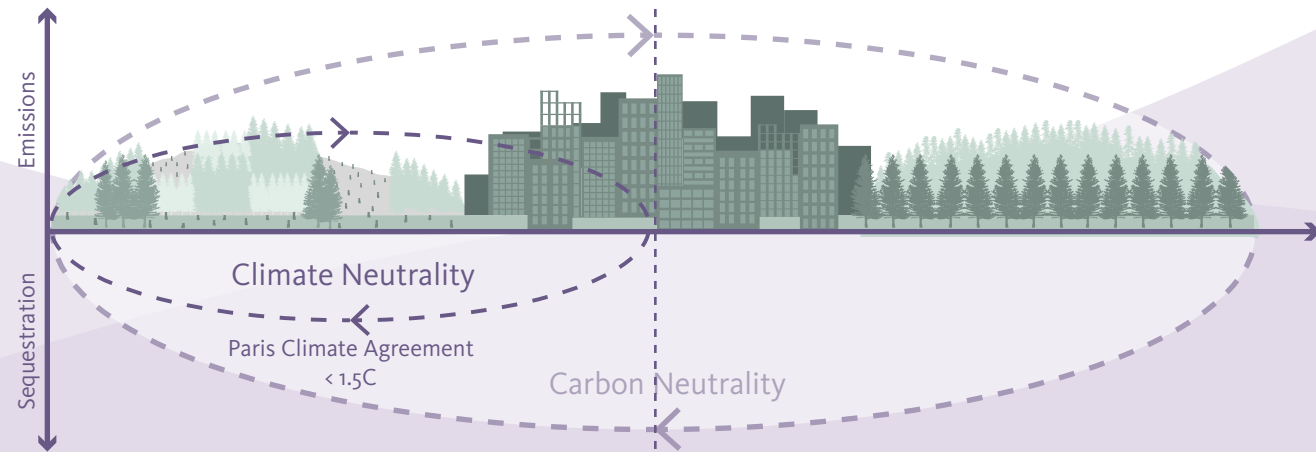
‘o/o’ approach (carbon neutral)

Assumes that carbon emissions, particularly at EOL, are balanced by sequestration in new forest growth. Consequently, there is (o) release and (o) uptake.

Most literature suggests the ‘-1/+1’ approach to assess biogenic carbon, which has been adopted in the North American wood product PCR (product category rule), so all current environmental product declarations (EPD) utilize this method.

Although the concept of carbon neutrality under steady-state forestry is logical, it is an oversimplification of reality, discounting the complexity of biogenic carbon flows. Furthermore, there is growing recognition that carbon neutrality may not always equate to climate neutrality as carbon emissions over a given life cycle do not assure

a neutral effect on the climate.¹⁹ Climate neutrality is an important frame of reference as it addresses climate change impacts relative to urgent timescale required to close the carbon emissions gap to prevent the worst effects of climate change.



Climate Neutrality

Assumes net global warming effect from all greenhouse gas sources is zero by balancing emissions with atmospheric removal and storage. Need short timescale.

Carbon Neutrality

Assumes net carbon emissions is zero and biogenic carbon emissions are offset by eventual plant regrowth and re-uptake. May require longer timescale.

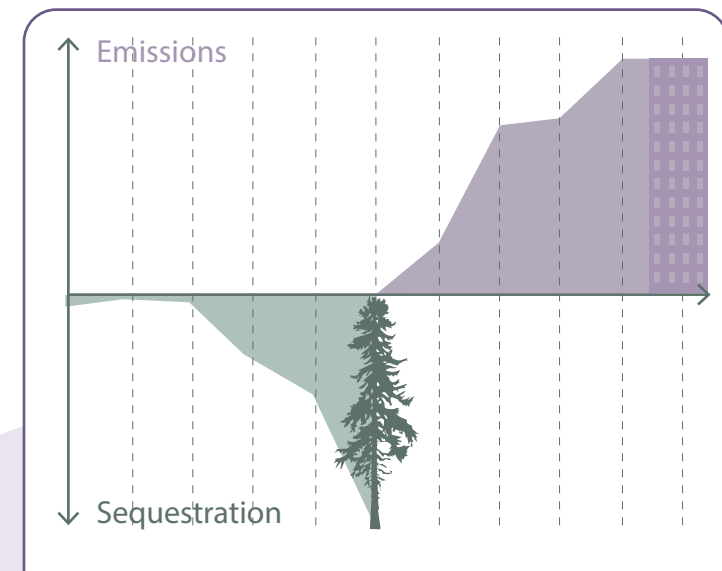
Traditional vs Dynamic LCA

The greatest criticisms of traditional LCAs, aside from their exclusion of biogenic carbon, are their failure to capture the timing of emissions, the influence of forest growth rates, inclusion of all forest carbon pools, and the effects from land use change. Lack of a temporal profile for carbon sequestration and emission (which occur at different times and in different life cycle stages) is a big missed opportunity in LCAs.⁵¹

DLCA accounts for the timing of all biogenic carbon flows before, during and after the service life of a building, including those in trees and soils. The timing of emissions is critical because if sequestration lags emissions, then

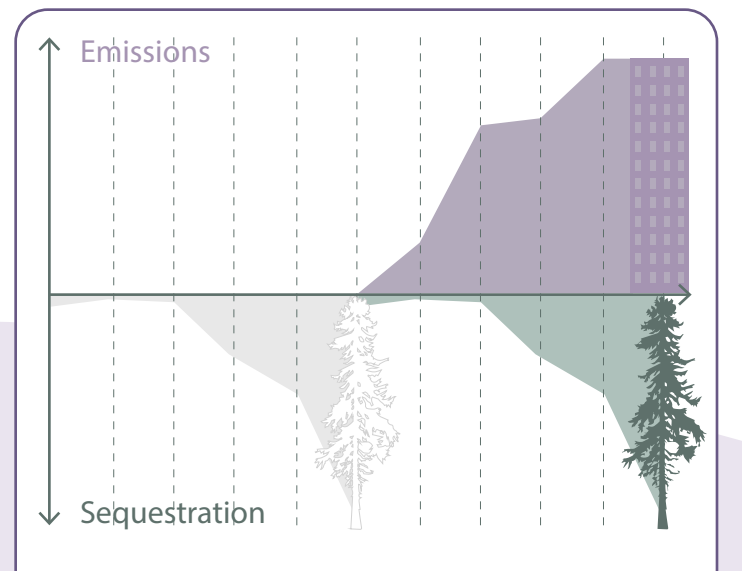
this carbon debt creates a warming effect. Excluding this temporal dimension is problematic when dealing with ever-changing carbon fluxes between terrestrial sinks and the atmosphere.⁵² In conventional LCA, sequestration is typically modeled in life cycle stage A as instantaneous which coincides with the steady-state goal of sustainable forest management but is irrespective of forest growth rate.³⁶ To counter this static perspective, there is a large consensus on the need for wider adoption of dynamic LCAs (DLCA).

Timing is important but there are two different approaches for the timing of emissions, and both have influence over the evaluation of wood products. Uncertainty lies on whether carbon is absorbed before or after HWP production.⁵³



Growth Pre-Harvest

The backward-looking approach models carbon sequestration preceding harvest, with the tree attributed to a timber product as the tree being harvested. This method follows the carbon cycle where biomass must grow first, and tracks the carbon physically stored in a timber product.



Regrowth After Harvest

The forward-looking approach models carbon sequestration occurring after harvest, with the tree attributed to a timber product as the tree grown to replace the harvested one. Impacts from building life cycle emissions and forest regrowth occur simultaneously.

Although the backward-looking approach may be more impressive given no carbon debt between the time of harvest and forest regrowth, many DLCA use the forward-looking approach which can be preferable from a sustainability perspective because of the focus on forest regrowth.⁵⁰ It should be noted however, that the forward-looking approach may assume that the same resources

input into growing the original tree were also input into growing the new tree which may not be the case. Uncertainty between the two approaches might be seen as a drawback given there is no consensus on which is preferable at the stand level, however it is suggested that further research modeling forest carbon sequestration at the landscape level can help to solve this problem.⁴⁹

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CARBON CLIMATE FORESTS

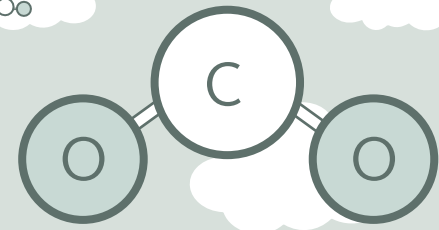
Key Points about Carbon, Climate and Forests

1. The amount and rate at which carbon cycles through forest and urban pools varies considerably over time. Soils generally store the largest share of carbon in forest ecosystems and therefore represent a significant carbon pool. Although difficult to measure, soil organic carbon can experience carbon losses from disturbance. Aboveground vegetation provides the second largest share of stored carbon in forests and these carbon stocks are more vulnerable to disturbances.
2. The availability of soil nutrients is key to site productivity. Repeated intensive forest management can deplete soil nutrients through the removal of biomass that would otherwise return to soils.
3. Climate change may enhance global forest growth in the short term due to the stimulating effect of elevated CO₂ and longer growing seasons, allowing for an increased photosynthesis; This photosynthetic benefit will likely be superseded by the long-term effects of climate change due to decreased productivity from warmer/drier conditions.
4. Climate-induced disturbances threaten forest resilience, the ability to recover post-disturbance, and have the potential to turn forests from carbon sinks to carbon sources. Altered disturbance patterns can outpace the ability of forests to successfully regenerate and therefore impede successful regeneration.
5. Insect outbreaks cause extensive tree mortality in a short amount of time.
6. Forest wildfires, increasing in frequency and severity, are part of a climate change feedback loop. As the climate warms, drought conditions reduce moisture from soils and trees fueling more severe burns that may also include losses of carbon from soil. Historic fire suppression and the absence of fuel reductions also contribute to more intense fires. These carbon emissions reinforce the climate dynamic leading to the next wildfires. However, forest carbon models have historically overstated atmospheric carbon contributions from wildfire due to the assumption that all trees are consumed, when, in fact, many trees remain standing and can maintain sequestered carbon for decades.
7. Salvage logging looks to recover the economic value of forests after disturbances. Generally, site regeneration is more successful the longer the time interval between disturbance and logging operations; the first few years after fire is when forest regeneration is at its most vulnerable. However, measures can be taken to mitigate the effects of salvage logging post-disturbance.
8. Biodiversity responds negatively, positively, or neutrally to disturbances, depending on the particular species. A diversity of stand structures could increase biodiversity by creating conditions more appealing to certain species of flora and fauna.
9. Forests have huge influence over water security and hydrological patterns over land. Managing forests for water is another important consideration that comes with synergies and trade-offs.

Carbon, Climate and Forests

Carbon Dioxide (CO₂)

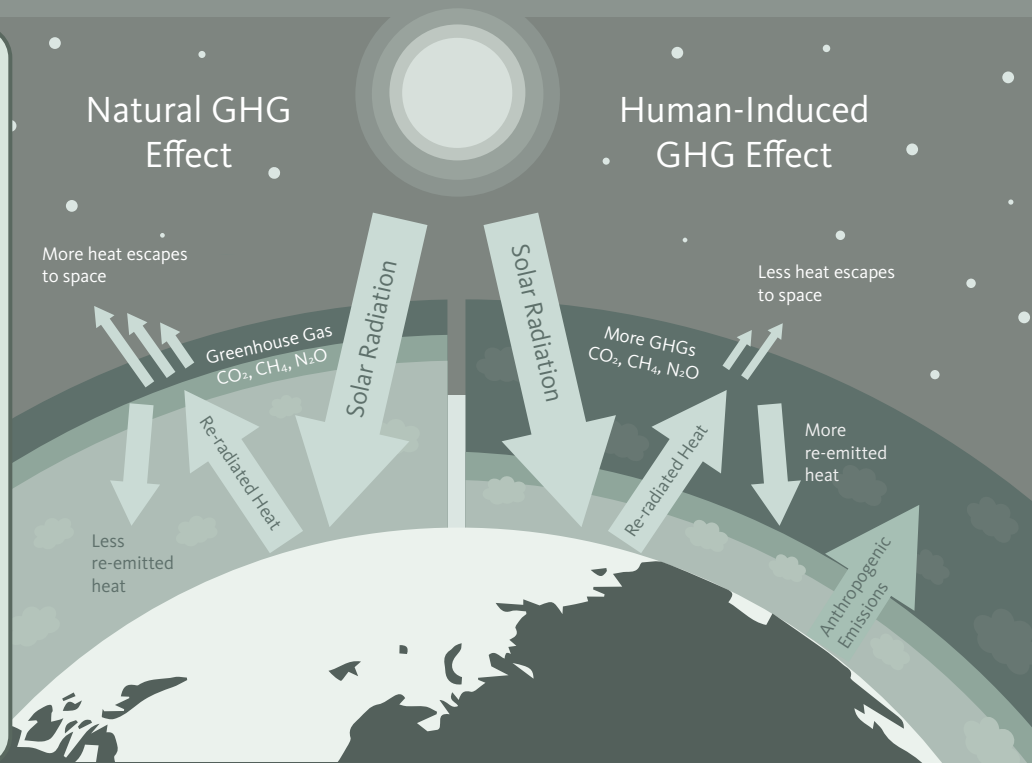
Is a chemical compound made up of one carbon atom and two oxygen atoms. CO₂ naturally exists in our atmosphere and is an important part of the carbon cycle, a set of processes that circulates carbon throughout our environment.



CO₂ and the Greenhouse Gas (GHG) Effect

GHGs are gases that trap heat in the atmosphere and help to regulate climate. Not only is CO₂ an important GHG in our atmosphere, but it is also the most prevalent.

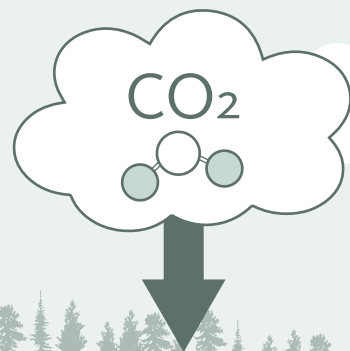
Human-related emissions, mainly from the combustion of fossil fuels for energy, are responsible for the increased concentrations of atmospheric CO₂. These high levels may substantially impact climate, threaten ecosystems, and alter natural processes like the carbon cycle.



Forests and Climate Change Mitigation

Climate change mitigation strategies look to reduce and avoid any further contribution of GHGs into the atmosphere from fossil fuels. One prominent strategy is to maximize forest carbon sequestration and storage as forests are considered critical terrestrial carbon sinks.

In recent decades, the world's forests have served as a net sink of carbon with living tree biomass accumulating most of it.¹

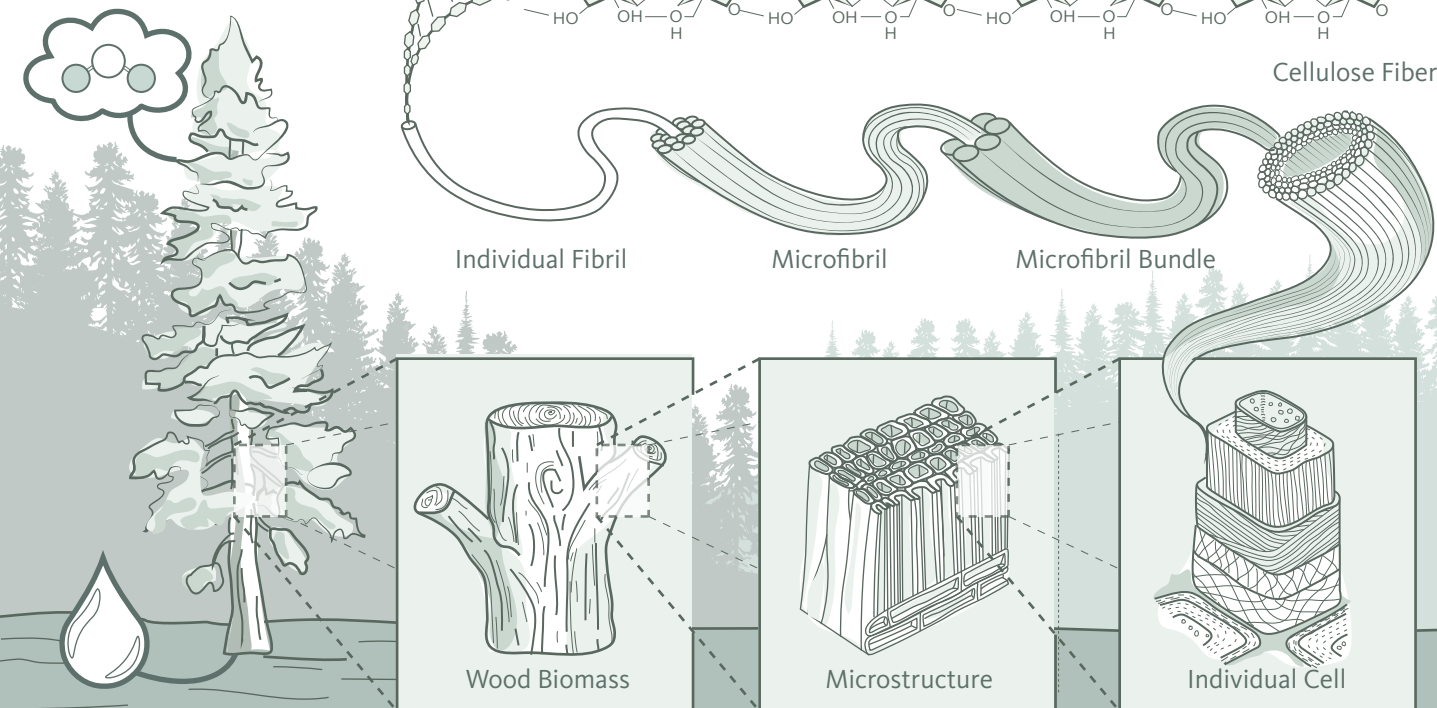
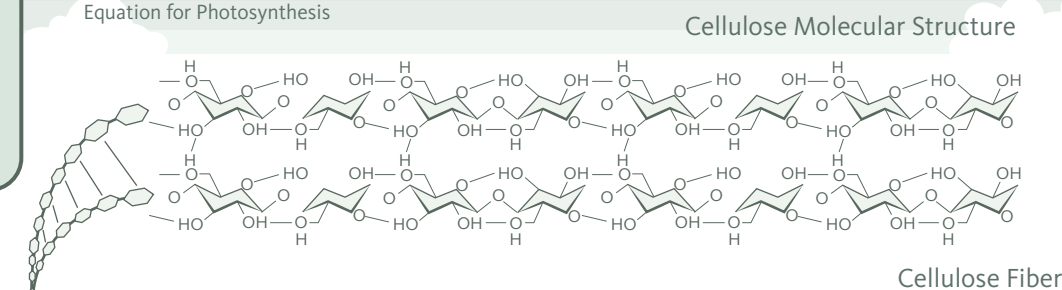
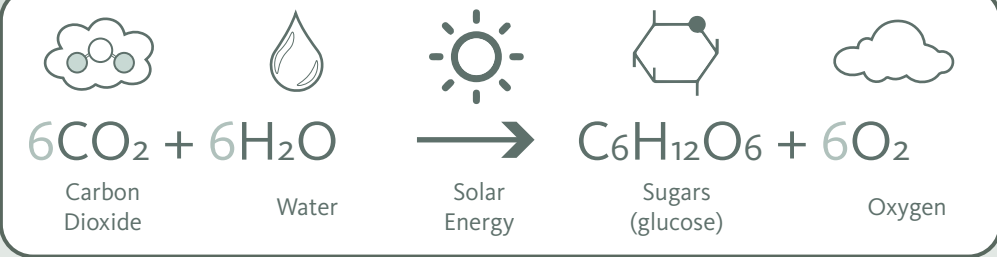


The Carbon Cycle: from Molecule to Forests

How do trees sequester carbon? It begins with photosynthesis

Photosynthesis

Is the carbon cycle process by which plants use sunlight to convert water and atmospheric CO₂ into oxygen and energy-rich organic compounds. Through biosynthesis, simple sugars are linked together to form the cellulose structure of trees and plants producing gains in biomass.



Biogenic Carbon

Is the term used to describe carbon stored in the growth of biomass through photosynthetic processes.

It is often assumed that the dry weight of a tree's biomass is 50% carbon although this is a rough assumption as a tree's carbon content varies between species, biomes, and tissue types.²



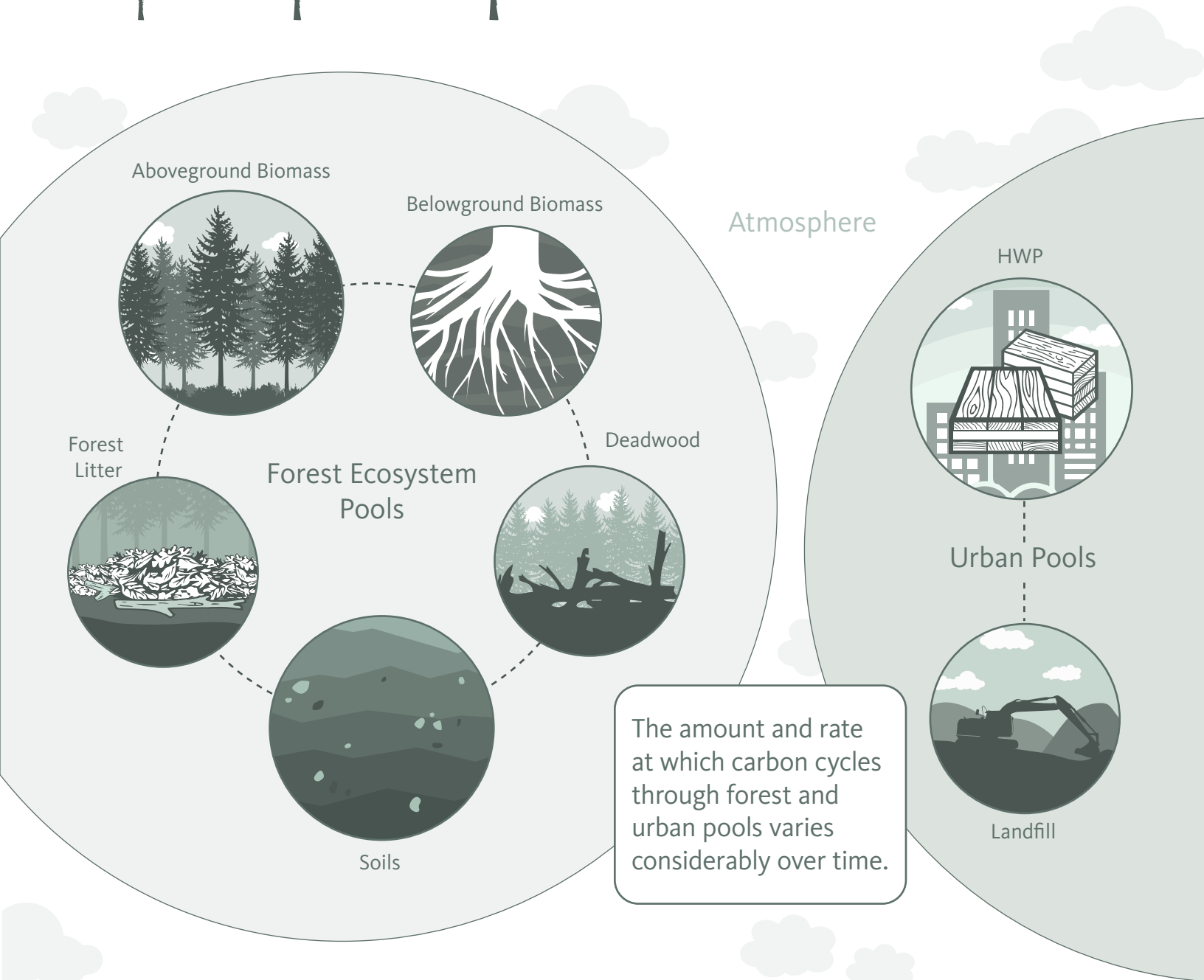
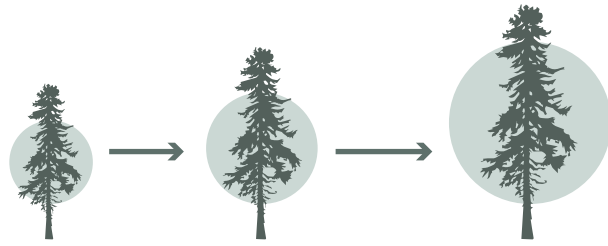
North American tree species can range from 46%-55% with softwood species generally having a higher carbon content than hardwood species.²

Respiration

Opposite to photosynthesis, respiration is the carbon cycle process that involves using sugars and oxygen from photosynthesis to produce energy for plant growth. As a result, some carbon is released back into the environment.

The Carbon Cycle: Carbon Pools

Over time, trees continue to grow, and sequester and store significant amounts of CO₂ away from the atmosphere, accumulating it as biomass.

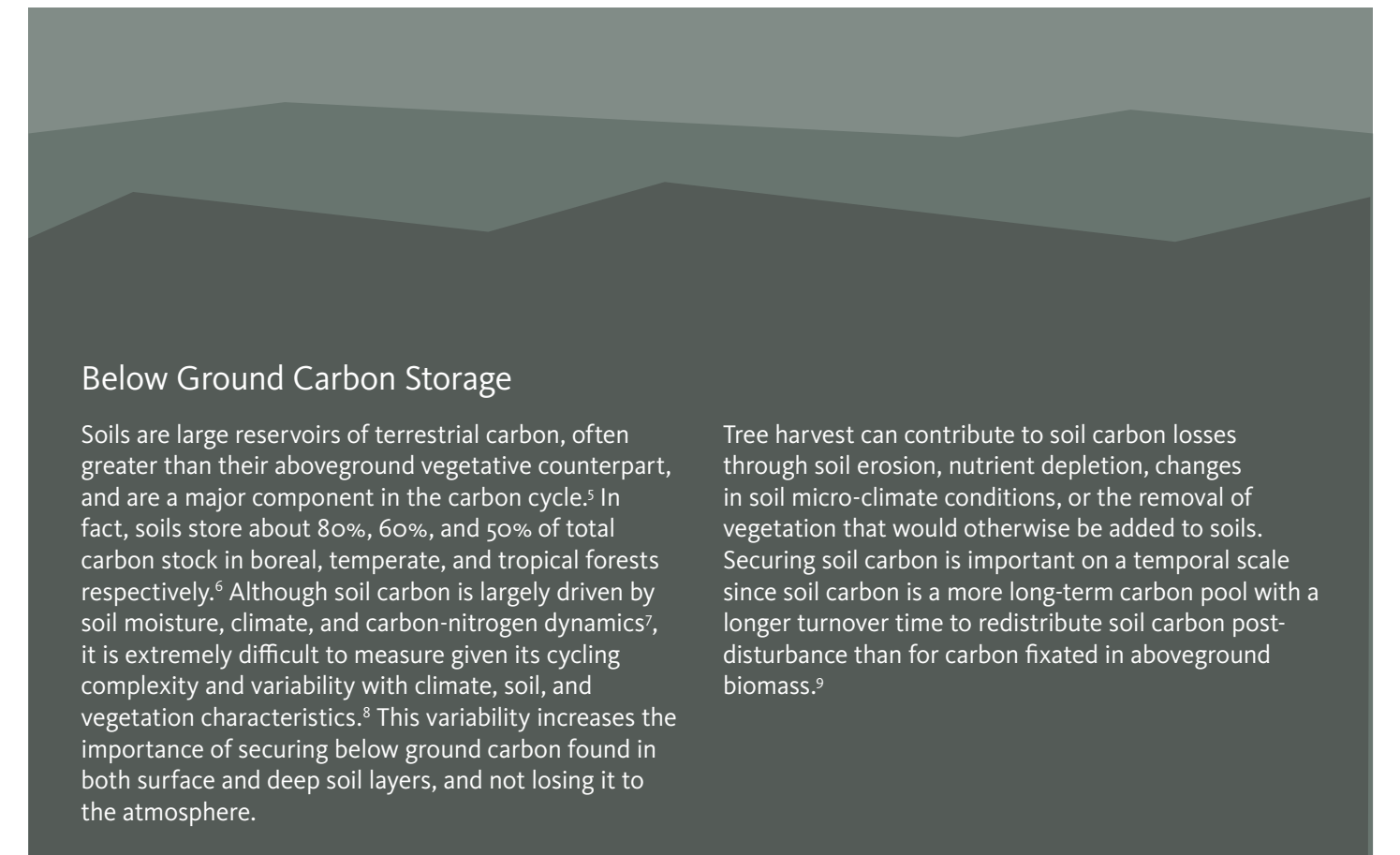
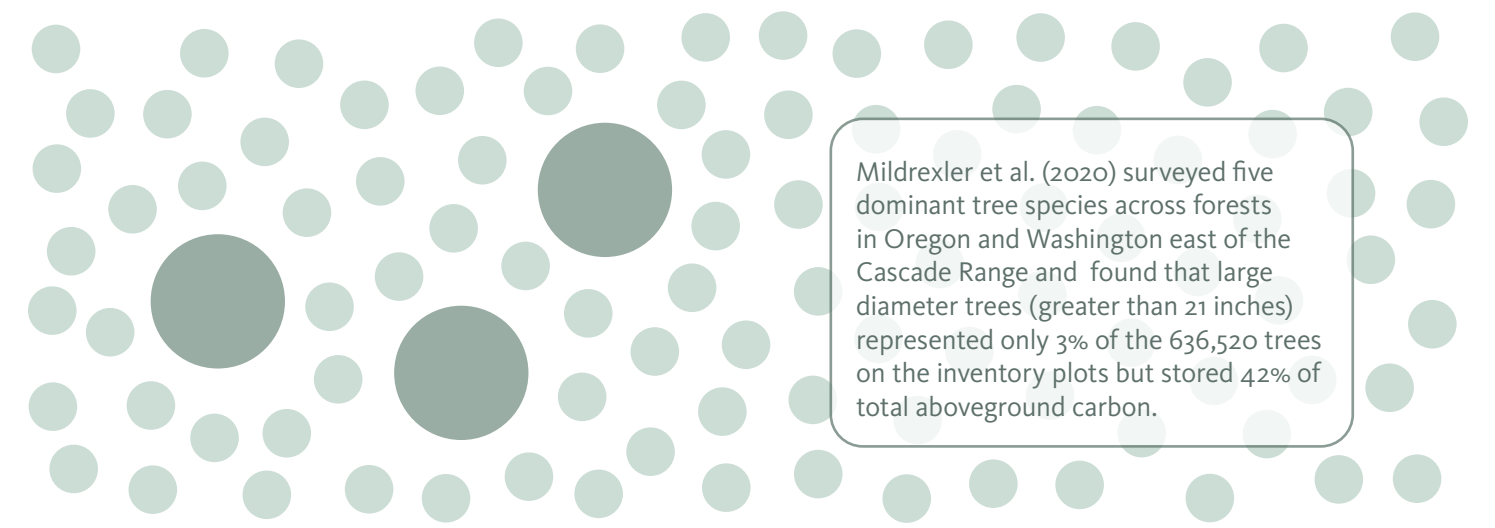


The Carbon Cycle: Two Important Reservoirs

Above Ground Carbon Storage

Aboveground biomass includes trees, plants and other leafy or woody vegetation. Forest carbon storage is highly dependent on the retention of large diameter trees, (diameter at breast height, “DBH,” greater than or equal to 21 inches). While these trees represent a small fraction of forest tree stock, they account for a significant portion of aboveground carbon storage. These large trees store

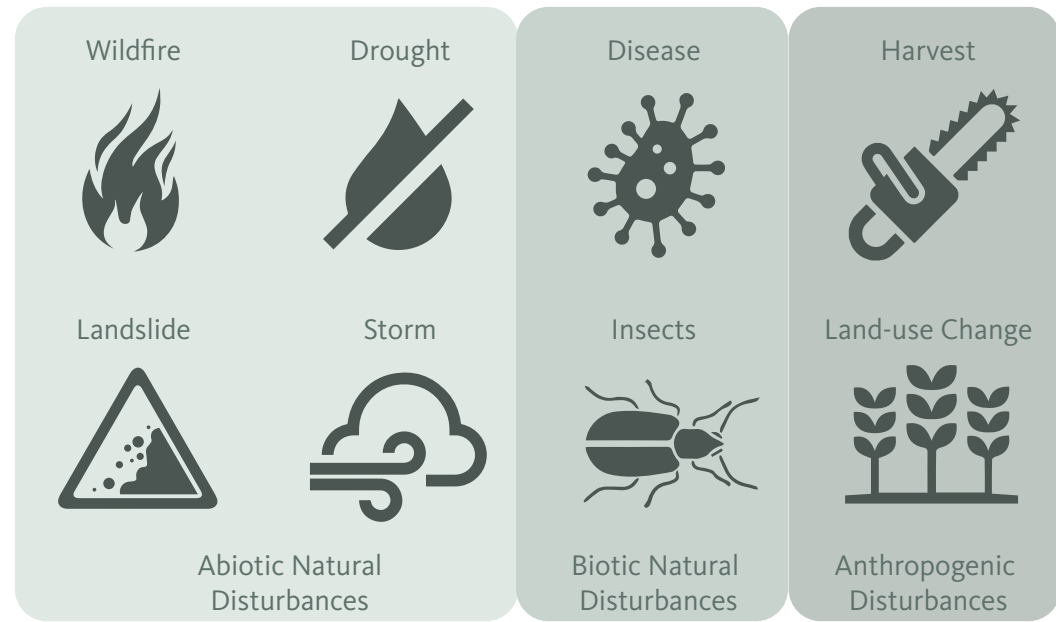
disproportional amounts of carbon, so much so, that carbon accumulated in one year’s growth of a large tree can equal to the that of the entire carbon stored in a medium sized tree. The harvest of large trees would not only remove massive amounts of biogenic carbon but can also be detrimental to ecosystem services such as forest resilience, micro-climate buffering, biodiversity, and water availability.⁴



Soils are large reservoirs of terrestrial carbon, often greater than their aboveground vegetative counterpart, and are a major component in the carbon cycle.⁵ In fact, soils store about 80%, 60%, and 50% of total carbon stock in boreal, temperate, and tropical forests respectively.⁶ Although soil carbon is largely driven by soil moisture, climate, and carbon-nitrogen dynamics⁷, it is extremely difficult to measure given its cycling complexity and variability with climate, soil, and vegetation characteristics.⁸ This variability increases the importance of securing below ground carbon found in both surface and deep soil layers, and not losing it to the atmosphere.

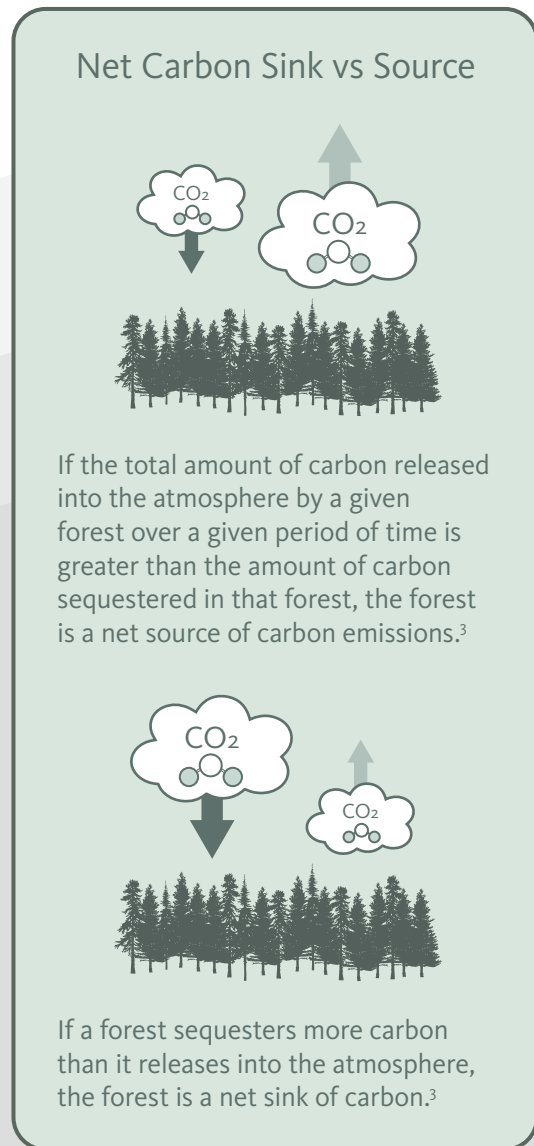
Tree harvest can contribute to soil carbon losses through soil erosion, nutrient depletion, changes in soil micro-climate conditions, or the removal of vegetation that would otherwise be added to soils. Securing soil carbon is important on a temporal scale since soil carbon is a more long-term carbon pool with a longer turnover time to redistribute soil carbon post-disturbance than for carbon fixated in aboveground biomass.⁹

The Carbon Cycle: Carbon Dynamics



Forest carbon dynamics are driven in large part by disturbances as they result in tree mortality and therefore a loss of biogenic carbon. Carbon lost in areas affected by disturbance may be offset over time assuming land use change is avoided and reforestation occurs.³

Forest carbon is constantly changing with tree growth and death.



Carbon Dynamics of US Forests³

About one-third of the United States is forested. The carbon density of these forests varies considerably due to factors such as climate, vegetation type and disturbance history.

Overall, U.S. forest carbon stocks have increased annually since 1990, making them a net sink of carbon.

The majority of forest carbon in 2020 was stored in the forest ecosystem pools (95%) with the remainder stored in the product pool.

Forest soils contained approximately 53% of total forest carbon in 2020, followed by aboveground biomass which contained approximately 26% of the total. Each of the other forest pools (i.e. belowground biomass, deadwood, forest litter) stored less than 6% of the total carbon.

58.7 billion metric tons of carbon stored in 2020

Carbon Distribution in US Forests (2020)

- Soils
- Aboveground Biomass
- Other

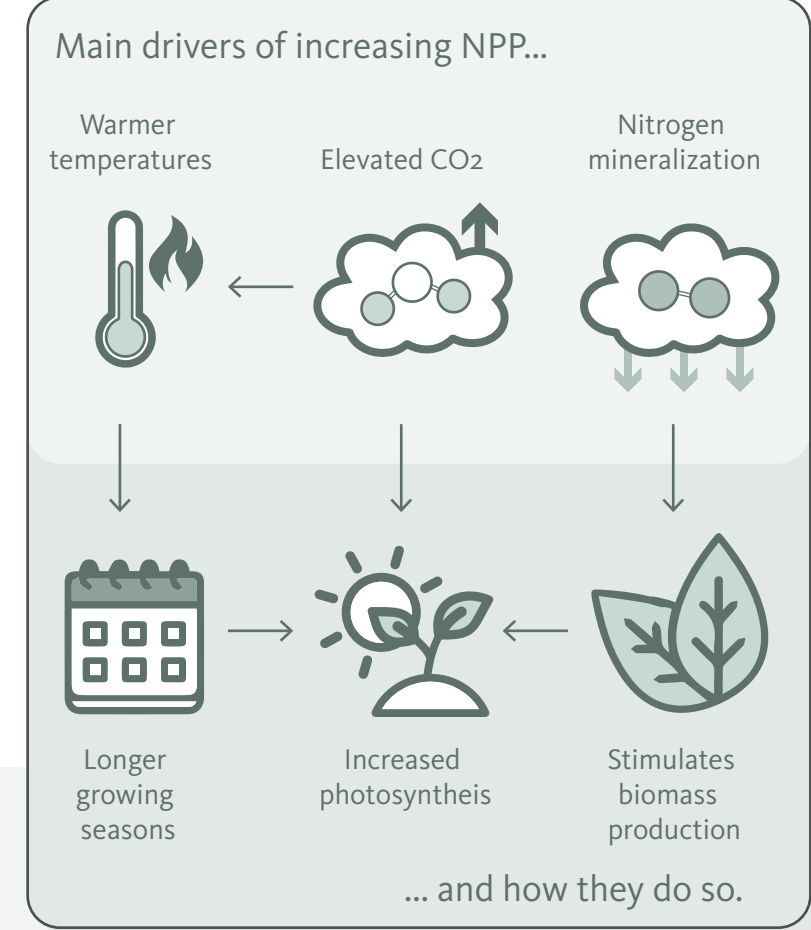
Climate Change Effects on Forest Ecosystems

Climate change may overall enhance global forest growth in the short-term.

Net Primary Productivity (NPP)

Describes how much CO₂ is taken in by vegetation during photosynthesis minus how much is released by respiration. It is an important aspect of the carbon cycle that serves to measure plant growth.

NPP is highly influenced by climate and atmospheric CO₂, both of which are responsible for plant growth and are expected to cause major changes to the global structure of forests and their ability to store carbon.¹⁰ Climate change may enhance global forest growth in the short term (particularly in the tropics) as elevated levels of CO₂ may increase rates of photosynthesis and therefore terrestrial carbon storage.^{11,12} This CO₂ effect is a significant negative feedback in the global carbon cycle, responsible for about 60% of the current terrestrial land sink.¹² It is important to note that this effect may vary for different forests across different regions.



The short-term benefits from carbon uptake in response to elevated CO₂ are not guaranteed in a hotter future and will likely be superseded by the increasing effects of climate change.

Can Trees Keep Up?

Elevated CO₂ and rising temperatures are a cause-and-effect relationship with opposing impacts on plant physiology. Although CO₂ enrichment may stimulate tree productivity, it is not clear to what extent this photosynthetic benefit is capable of offsetting the physiological stresses imposed by higher temperatures.¹³ The balance between the two drivers will likely depend on the degree to which physiological processes are affected by rising CO₂ and if they can accommodate accompanying increases in temperature.¹⁴ The combined effect of elevated CO₂ and high temperatures can have a neutralizing effect in warmer futures¹⁵, but this threshold response will unlikely be the case in even hotter futures as forests reach their climatic tolerances.^{16,17}

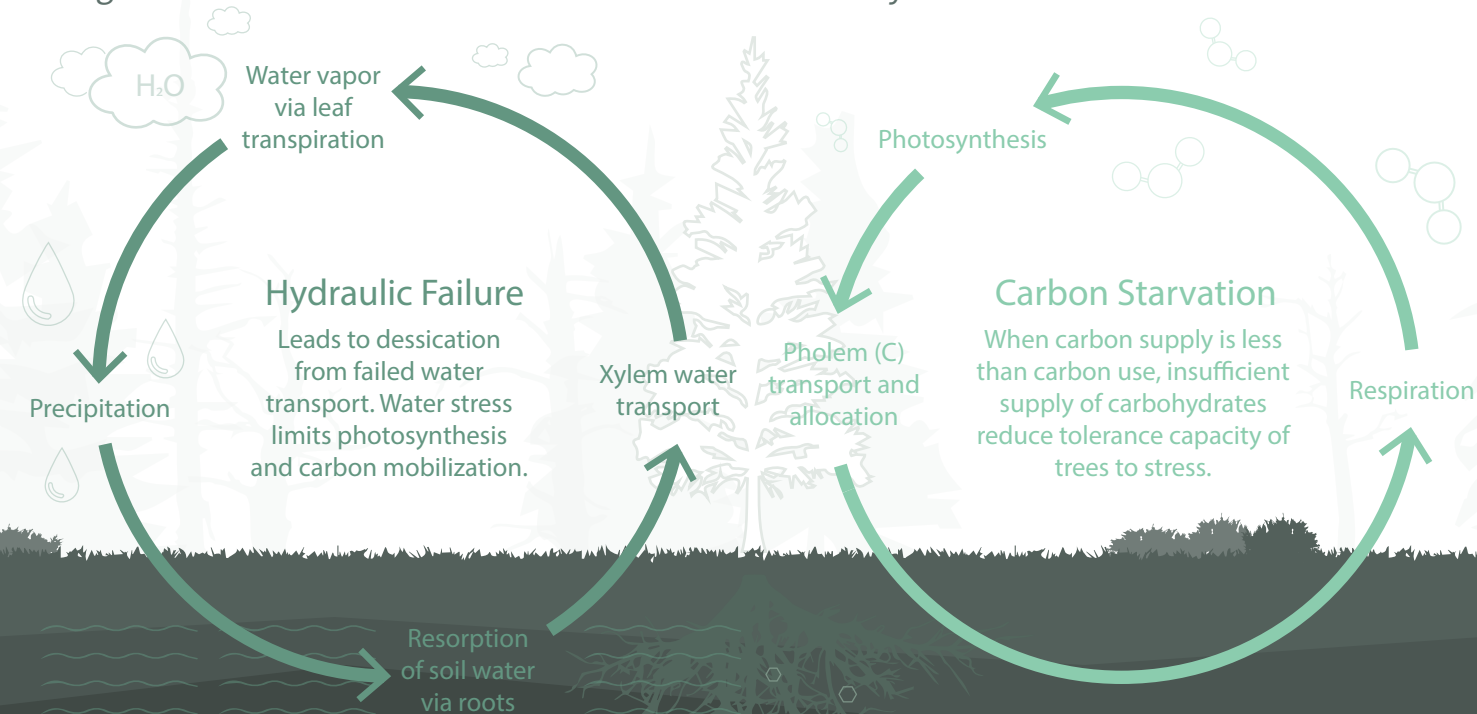


Climate Change Effects on Forest Ecosystems

The stimulatory effect of elevated CO₂ on carbon storage could slow considerably this century and will unlikely be able to compensate for the detrimental effects of long-term drought on tree productivity.¹⁸ Despite recent tree growth correlated to elevated CO₂, large scale mortality events have been attributed to warmer and drier conditions as longer droughts increase the risk of tree mortality.¹⁴ Even in the absence of fire, drought conditions alone can be responsible for gradual tree die-off¹⁹ via increased moisture stress, evaporative demand, and reduced winter snowpack.²⁰ Increasing moisture deficits will likely contribute to declines in tree area to levels lower than have occurred

historically.²¹ A direct consequence of extensive tree die-off includes major carbon losses to the atmosphere, although ecological regime shifts may follow. Drought-stress will likely vary from species to species but increased mortality of sensitive species may change forest successional pathways and undermine forest resilience.²² Even drought tolerant species like Douglas-fir, a species preferred by industry for its structural characteristics, are vulnerable to drought conditions.^{23,24} As dry regions are likely to become drier, and tree vigor is reduced, a possible outcome may be a decrease in harvestable stands.²⁵

Drought-Induced Interactions of tree carbon and water dynamics²⁶



It is also important to consider the role of elevated CO₂ between plant and soil carbon storage. Trees increase their biomass by mining soils for nutrients²⁷, primarily nitrogen, which is considered the primary limiting growth nutrient in many forests.²⁸ Young trees may benefit from CO₂ enrichment, however concern is placed on mature trees and whether they will be able to remain carbon sinks. Mature trees can take up more CO₂, but sequestration is ultimately limited by the availability of other nutrients and balanced by respiration.²⁹ While soils exhibit large variability, tree nutrient acquisition under elevated CO₂ can best be described by an overall negative relationship with soil carbon as the mining for soil nutrients reduces soil carbon.²⁷ Nutrient limitations can lower carbon gains in ecosystem modeling substantially and highlights the role nutrients play in carbon sequestration.

Disturbance and Ecological Resilience

A warming climate alone can lead to extensive tree mortality over time, however climate-driven disturbances may catalyze major change and urgently threaten carbon storage.

Increasing frequency and severity of disturbances are evident in many forest ecosystems around the world with future changes most likely to be pronounced in temperate and boreal biomes. Warmer and drier conditions amplify the risk of exposing forests to fire, drought, and insect outbreaks while warmer and wetter conditions increase exposure to windfall and pathogens.³⁰ Ultimately, altered

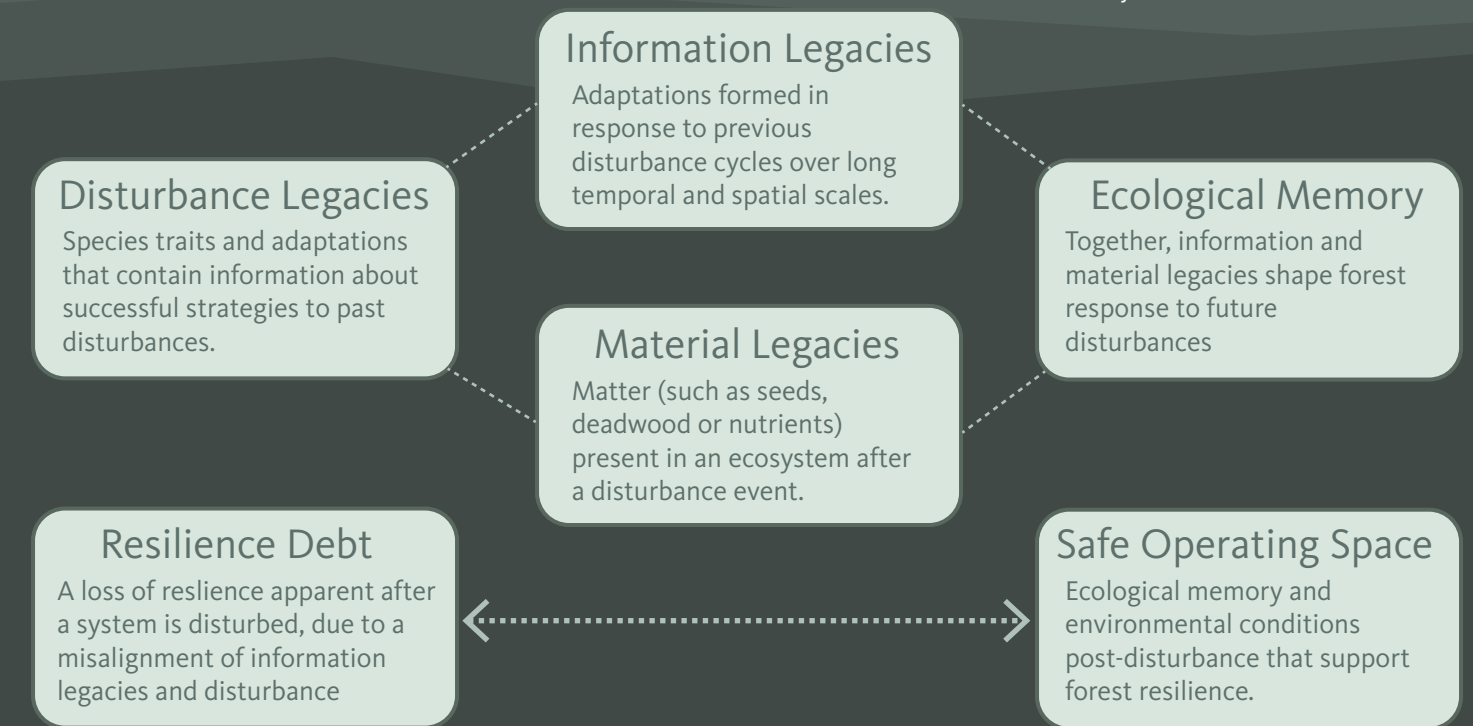
disturbance patterns may affect several forest carbon dynamics including tree regeneration, forest succession and composition, ecosystem productivity, and carbon storage. Regarding carbon storage, disturbances lead to increased levels of tree mortality and have the potential to turn some forests from carbon sinks into carbon sources.³¹

Directional climate change can erode the ecological memory of forests to future disturbances and create a resilience debt.

Direct impacts to forest resilience, the ability of forests to recover after a disturbance, manifest through climate and may affect vegetation growth, reproduction, distribution and survival.²² Climate-driven disturbances will likely catalyze rapid reorganization of aboveground biomass through a series of abrupt and episodic events that may

undermine forest resilience.³² Ecological memory of pre-disturbance conditions are essential to forest resilience by which remaining disturbance legacies (information on successful strategies to past disturbances via species adaptations) carry on to support recovery.³³

Terminology and definitions adapted from Johnstone et al. 2016



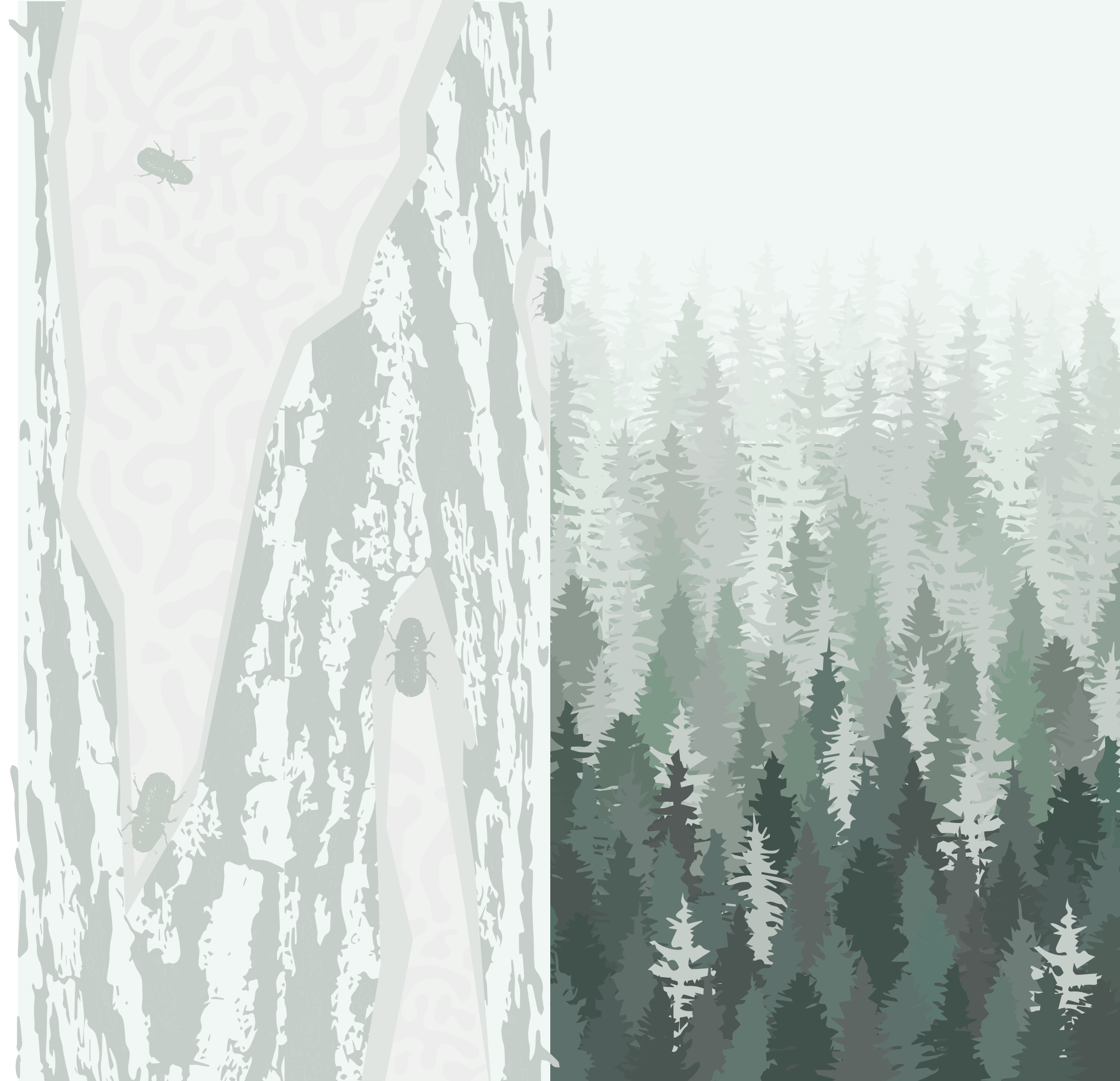
Insects

Insect outbreak is a major natural disturbance capable of tree mortality over large swaths of forest in a short period of time

Predicting the effects of climate-induced insect outbreak are very complex due to interactions and uncertainties between changing climate conditions and differing responses by both tree and insect species.³⁴ Furthermore, effects of climate vary greatly between insect species (mainly determined by feeding guild).³⁵ As a result, general conclusions or future predictions on climate induced insect outbreak are very difficult. Research on tree mortality has generally studied the effects of drought and insect outbreak independently even though both are closely related with their combined effects greater than either disturbance alone, yet ecosystem models do not accurately reflect climate-insect linkages.³⁶

Insects are directly affected by temperature, and indirectly by tree responses to climate.³⁷ The effects of a warming climate are clear in some insects where higher temperatures can shorten insect generation times and increase reproductive and survival rates conducive to outbreaking populations.³⁵ This outcome, however, cannot be generalized to all insect species, and it is therefore suggested that studies conduct species-specific models.³⁸ Climate also has an indirect effect on insect population growth and spread via drought stress on host trees through changes in tree physiology and spatial patterns.³⁶

Bark beetles are a prominent aggressive insect in temperate and boreal biomes, and evidence points to climate change and subsequent drought as a driver for their increased recent outbreaks.³⁹ As wood borers, bark beetles penetrate tree stems in numbers, forming chambers and introducing mold (responsible for blue stains), that eventually overcome tree defense's and lead to tree death. Drought increases the vulnerability of trees to weakened conditions while associated high temperatures accelerate beetle population growth. Under a warming climate, several species of bark beetles and defoliators have expanded their range to more northern latitudes with higher reproductive rates than in the past; in doing so, not only are preferred tree species at risk, but so are novel tree species that are not co-adapted to insect attack.³⁴ As a result, insect outbreaks may become more severe as tree species diversity declines at higher latitudes.³⁶ While drought may support bark beetle outbreaks, it is unlikely to support their future activity in naturally vegetated areas given diversity in tree composition from emerging forest succession and therefore limited preferred tree species by the insect.³⁹



Wildfire

Wildfires affect all biomes, yet forests alone are responsible for nearly a quarter of all fire related emissions.⁴⁰ Carbon storage in both vegetation and soils is vulnerable to wildfire because tree mortality and soil erosion following combustion can lead to increased release of CO₂ and decreased future uptake.⁴¹ The immediate release of CO₂

from biomass combustion advances atmospheric warming, leading to climatic conditions that reinforce the next wildfires. Other ecological services affected by wildfire include air and water quality, biodiversity and habitat, tree regeneration dynamics, and timber supply.

Three characteristics to better understand wildfire dynamics:⁴⁰



Area Burned

Although the area of land burned globally has declined since 1990, the picture varies around the world. Increasing drought conditions can easily reverse this trend.



Frequency

Fire seasons are longer, more common, and increasingly unpredictable. Frequent fires prevent forests from maturing and reaching their carbon storage potential.



Intensity

Drought conditions reduce moisture from soils and trees fueling more severe burns. Intense burns may lead to losses of soil carbon.

Wildfire in Western North American Forests

North American forests, particularly those of the northwest, are invaluable carbon sinks vulnerable to wildfire as tree mortality and soil erosion from combustion can lead to increased carbon release and decreased carbon uptake.⁴¹ These forests were historically shaped by wildfire generally characterized by high frequency-low intensity fires in dry forests, and by infrequent, high-intensity fires in moist forests.⁴²⁻⁴³ Years of fire suppression and consequent accumulation of both live and dead surface fuels have created a fire deficit (especially in dry, low elevation, mixed conifer forests) where climate-driven fire behavior has surpassed that to which long-lived dominant conifer species are adapted to.⁴⁴ Cool and wet forests may be relatively resilient, but not completely invulnerable to wildfire, if they can withstand variations of fire behavior without losing the potential to return to pre-fire conditions. Forests on the drier end of the spectrum, however, may be near a tipping point where small changes in fire behavior or recovery dynamics can lead to extensive landscape changes.²⁰ Vegetative spatial patterns in fire-excluded areas no longer reflect the landscape heterogeneity once maintained by fire⁴⁵; disruption of historical fire regimes in

conjunction with the amplifying effects of climate change have left forests increasingly vulnerable to severe drought and fire conditions and could lead to irreversible changes in ecosystem structure and function.⁴²

Fire activity in western North American forests is expected to increase amidst climate change with profound effects on both regional forest resilience^{21,46} and even reduced NPP in other parts of the world.⁴⁷ Forest resilience to wildfire is strongly dependent on tree regeneration, a measurement contingent on adequate seed sources, favorable seedbed conditions, favorable post-fire conditions and long-term climate.⁴⁸ Given increasing temperatures, associated water stress, and escalating wildfire intensity, there are increasingly fewer opportunities for successful seedling establishment after wildfire and a greater likelihood for regeneration failure for sites at their climatic tolerances.^{49,50} This draws concern for abrupt fire-facilitated conversion of forests to non-forests, a result which is not only becoming more prevalent⁴⁴, but also affects ecosystem services such as carbon storage, watershed integrity, biodiversity, wood production and recreation.¹⁹

Fire-Facilitated Conversion to Non-Forest Landscapes



1. Extensive Mortality of Mature Trees

- Drought conditions lend to increased vulnerability and susceptibility to tree mortality before and during fire.
- High intensity fires create large patch openings which are a particular problem for conifers that rely on seed dispersal over short distances⁴⁸; limited seed dispersal extends recovery time.²⁰
- Fire-driven conversion from conifer-dominated systems towards less productive early-seral landscapes (dominated by re-sprouting broadleaf species, shrubs, grasses and downed deadwood).

2. Hindered Forest Recovery

- Fewer and more distant trees reduce seed availability and encourages growth of early-seral vegetation.⁴⁸
- High severity fires can influence micro-climate and soil properties. Heat and reduced moisture minimize post-fire windows with suitable climate for conifer seedling establishment. Regeneration failure is likely to occur on sites at their climatic tolerance.^{44,49,50}
- Competition from resilient re-sprouting grasses and shrubs can severely constrain conifer seedling establishment.⁴³

Feedbacks

Positive Feedbacks

- Dense, flammable early-seral vegetation is prone to re-burning, eliminating conifer seedlings, resetting regeneration, and maintaining non-forest communities.⁴⁴
- Beyond CO₂, trace gases present in smoke plumes from biomass combustion result in the formation of organic aerosols and tropospheric ozone (O₃), a potent GHG. The formation and emissions of these gases reinforce warming trends.^{41,52,53}

Negative Feedbacks

- Periods of low flammability and decreased fuels provide some resistance by providing fire-free periods for forest recovery.

Salvage Logging

Downed deadwood after a disturbance creates both opportunities and risks which may present themselves in the short term (less than 5 years) or in the long term (more than 5 years). The primary motivations for salvage logging are to recover a forest's economic value and to reduce the

risk of future disturbances. Salvage logging, however, affects disturbed forests through mechanical disturbance caused by logging operations and by altering or removing disturbance legacies.⁵⁴

Salvage Logging on Site Ecology and Regeneration

Negative Short-Term Consequences

Immediate consequences of post-fire logging are generally negative⁵⁴ impacting soil erosion, nutrient cycling, and changes in hydrological regimes, and regeneration.⁵⁵ Burned sites are already at a greater sensitivity to soil erosion and surface runoff, yet the passing of heavy machinery associated with ground-based logging operations can lead to soil compaction and ground cover removal that increase the rate of such consequences. Reducing runoff and erosion

from skid and feller-buncher trails may protect watershed security.⁵⁶ Mechanical disturbance may further impede successful regeneration by burying or damaging emerging young seedlings and eliminating disturbance legacies such as viable remaining seed sources.^{48,55} It should be noted that short term post-fire vegetation assemblages may not represent long term regeneration dynamics.

Neutral – Slightly Positive Long-Term Effects

Ecological responses to salvage logging vary with time elapsed between the disturbance and logging⁵⁵; post-fire logging does not necessarily produce long-term ecosystem degradation or alternative recovery pathways.⁵⁷ Although post-fire logging can impede regeneration of seedlings, it can also reduce competition from re-sprouting grass and shrub species by removing herbaceous cover and exposing mineral seedbed for conifer establishment. In the long-term, salvage logging can leave a neutral to slightly positive effect on post-disturbance regeneration density when seed sources are available, post-fire weather conditions are favorable, and harvest operations do not negatively affect soils.⁴⁸



Light touch management practices that limit damage to soils, like hand-felling and logging over snow or frozen ground, may limit damage to vegetation and encourage rapid recovery.⁵⁷

Salvage-logging commonly occurs soon after disturbance to avoid declining quality of wood. Mitigating efforts to salvage-logging, however, are more effective the longer operations are withheld post-disturbance with consequences such as delayed recovery most prominent within the first few years of disturbance.

Salvage Logging on reducing risk of future disturbances:

Post-fire logging may not only mitigate the risk of future fires but can also significantly reduce levels of surface fuels in forests regenerating from wildfire in a way that mimics original fire regimes⁴⁶, although the extent to which it does so will depend on a variety of management objectives as well as scale and intensity of operations.^{48,57} Salvage logging decreases large surface fuels which may help to mitigate wildfire intensity in the long term, however an abundance of fine fuels are generated in the short term and increase the risk of fire after harvest unless appropriate fuel-reduction treatments are implemented.^{54,58}

Salvage Logging on Biodiversity

Deadwood, particularly snags, are important disturbance legacies and their removal can have profound effects on biodiversity.⁵⁹ Although the removal of downed deadwood negatively affects saproxylic (deadwood dependent) species like insects and fungi⁶⁰, other species may benefit from altered stand structure and vegetative ground cover. This mixed result is true of bird species where cavity-nesting birds commonly associated with burned forests, are negatively impacted by salvage logging, while open-habitat bird species respond neutrally or positively to salvage logging. The effects of salvage logging are even more pronounced for invertebrates. Insects are often abundant following fire and are critical elements of post-fire landscapes, serving as food to insectivorous birds, advancing the decay of deadwood, and influencing soil nutrient cycling.⁶¹

Fuel reduction treatments could contribute to long-term restoration in dry coniferous forests by restoring surface fuels to levels more consistent with low and mixed-severity fire regimes.⁵⁸ Fuel treatments are unlikely to be effective in moist forests and could undermine ecological integrity of those ecosystems.⁴²

Since fuel reduction treatments cannot address all forests,⁴² extracting wood from stands deemed most susceptible to wildfire while retaining deadwood in more ecologically sensitive places such as riparian areas may help to balance wood supply, fuel loads and ecosystem services.⁵⁴

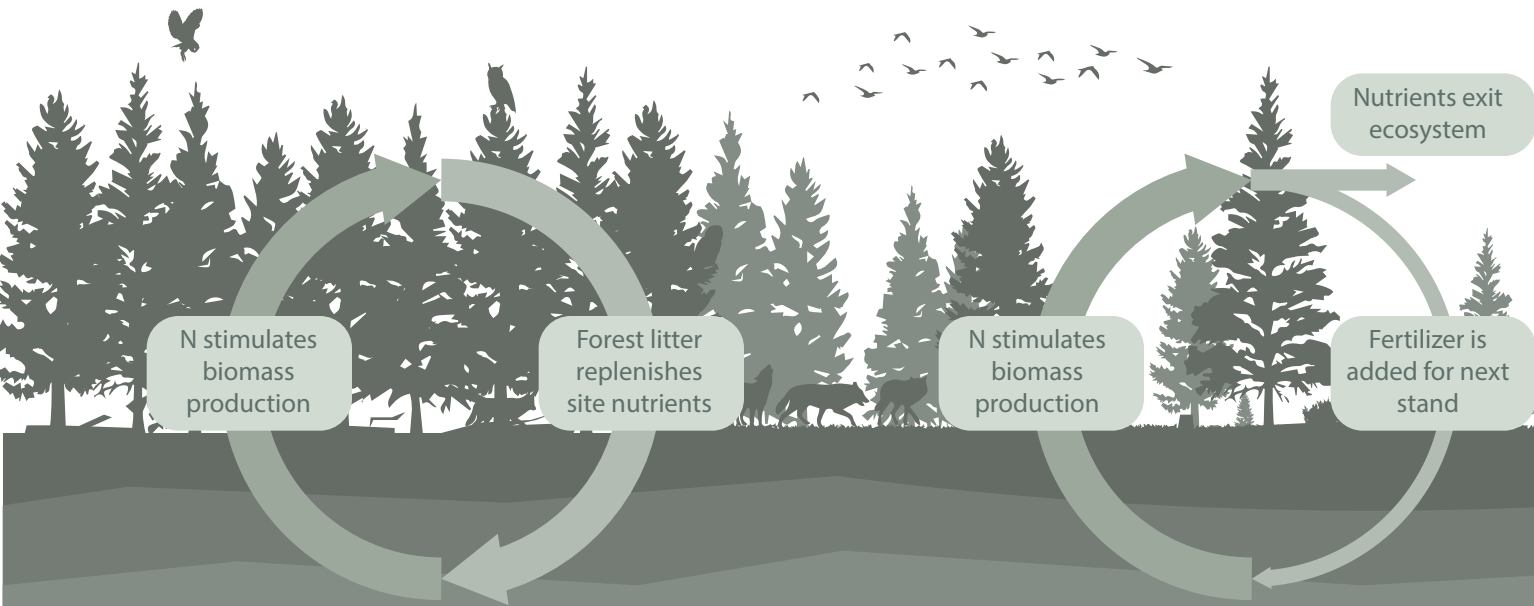


Effects of Harvest on Forest Ecosystems

Biodiversity

Managing forests for carbon storage, wood supply, and biodiversity involves trade-offs and may result in a complex mix of either complementary, competitive or neutral relationships.⁶² Greater biodiversity is often assumed by leaving forests alone, a method which coincidentally favors greater forest carbon storage, but maximum carbon storage does not mean maximum biodiversity since different species

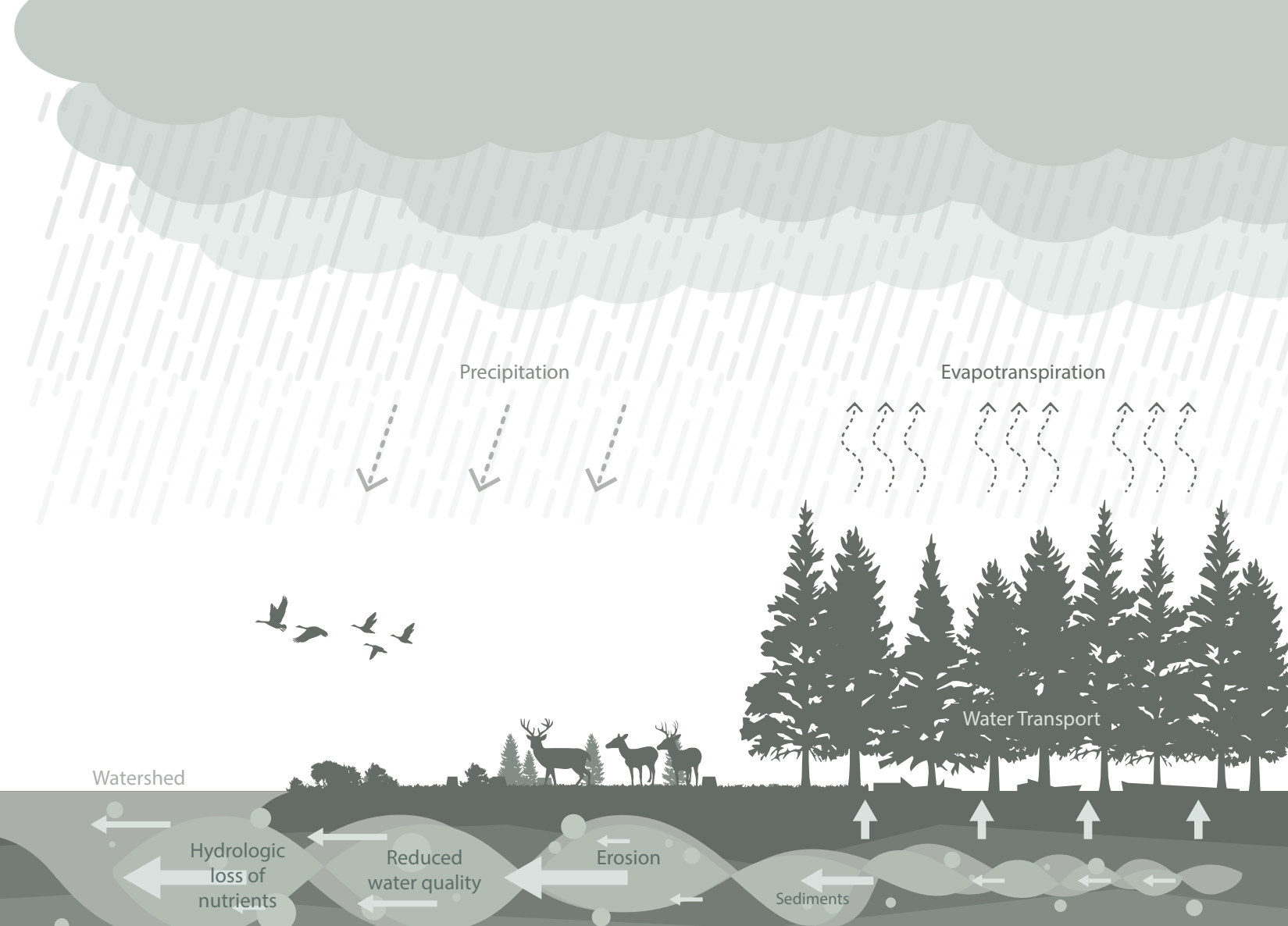
require different forest structures.^{63,64} Although a diversity of forest structures will result in varying carbon carrying capacities, active forest management may be an important tool to balance forest structures in relation to harvest intensity, frequency, and carbon storage potential.



Soil Carbon and Nutrients

Nutrients enter forest ecosystems by atmospheric deposition and the weathering of geologic substrates, allowing forests to maintain high net primary productivity and regenerate after disturbances. Harvest over the last couple of centuries has been a rather large new disturbance leaving much less nutrients behind compared to natural disturbances that were the main drivers of forest change over the last ten thousand years.⁶⁵ Given that soil carbon dynamics are strongly coupled to nitrogen cycling³, the availability of soil nutrients in forest ecosystems is crucial to consider for understanding the long-term effects of forest management practices. Nitrogen, which helps to stimulate biomass production, is abundant in our atmosphere and yet, is largely inaccessible because it exists in a gaseous form (N₂) not usable by plants. As such, N₂ must undergo nitrogen fixation (by soil micro-organisms) which converts nitrogen into usable compounds that can then be absorbed by plant root systems. Due to the limited availability of nitrogen, the element is often considered the primary growth limiting nutrient in forests.²⁸

Although the long-term effects of forest management on soil carbon are highly variable and remain unclear⁶⁶, intensive forest management can negatively influence soil organic carbon and nitrogen stocks in some or all soil layers^{67,68,69} and may contribute to their depletion through erosion, changes in micro-climate, hydrological losses, and the removal of vegetation that would otherwise be returned to soils.⁷⁰ Intense harvest followed by short rotations, which removes nutrients with little time for recovery, pose concerns for future stands regarding their fertility and carbon storage capability.^{65,66} Since tree and soil carbon pools in managed forests are linked, the trade-off between maximizing harvest and maintaining soil carbon stock makes it difficult from a climate change mitigation perspective, but from a carbon storage perspective, soil carbon is more secure as aboveground biomass is at greater risk to losses from disturbances.⁷¹



Hydrology

Like with flows of carbon, forests also regulate flows of water. Through evapotranspiration, forests recharge atmospheric moisture and play a role in precipitation patterns over land.⁷² On the ground, trees act like sponges, absorbing and storing water, thereby imposing a direct effect on stream flow quantity, quality, and timing. Forests help to purify water by minimizing soil erosion thereby reducing sediment and pollutants. Since soil erosion is generally the greatest risk to water quality associated with harvesting, healthy soils are key.⁷³ Given its higher risk of soil degradation, even-aged management such as clear-cutting can negatively impact water quality as well as its quantity and timing of stream flows.⁷⁴ Fast growing plantations are efficient in terms of wood production per unit volume of water but they still require a large amount of water and may be inappropriate in regions with low water availability.⁷³ Conversely, harvest strategies that leave more forest cover and less soil disturbance such as uneven-aged management utilizing thinning and selective harvest practices, not only

pose less of a risk on water quality but also help to restore degraded areas.⁷⁵

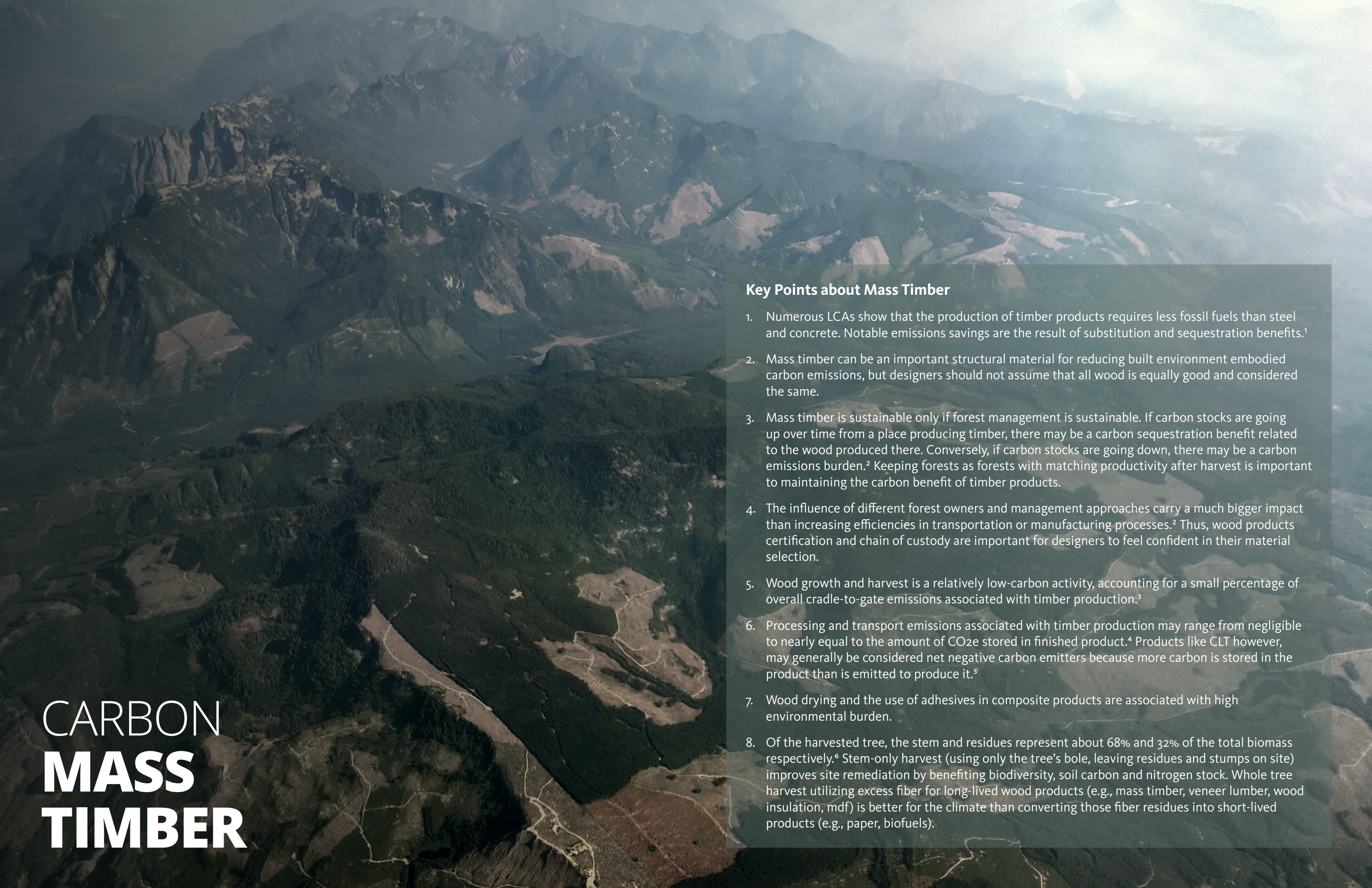
Managing forests for water brings both synergies and trade-offs. In terms of carbon, although an increase in evapotranspiration will generate less water across the landscape, carbon sequestration will increase in the growth of trees. Regarding biodiversity, the availability of clean water is essential for both terrestrial and aquatic wildlife communities. Forests managed for water can also produce opportunities for recreational and cultural services. While a lot of benefits can come from managing forests for water, it is necessary to understand how watersheds respond to changes in forest cover.⁷³

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An aerial photograph of a mountain range with a river valley. The mountains are rugged and covered in dense green forests. A river winds through the valley floor. The sky is hazy, suggesting a high-altitude or mountain environment.

CARBON MASS TIMBER

Key Points about Mass Timber

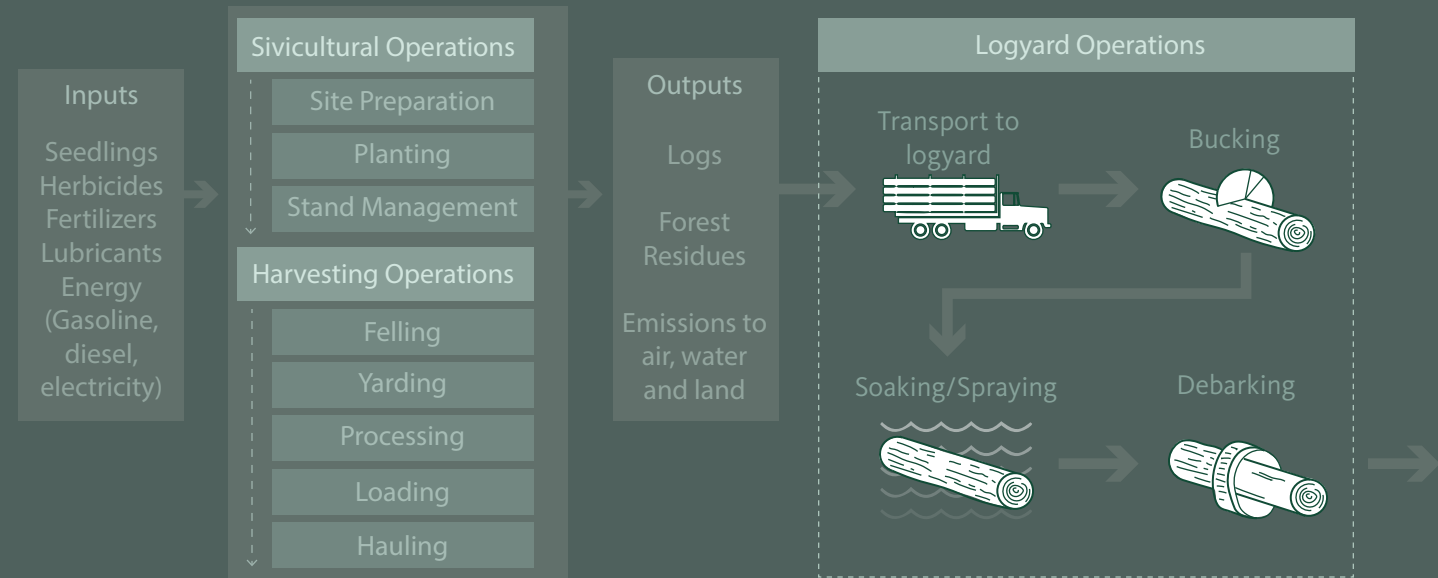
1. Numerous LCAs show that the production of timber products requires less fossil fuels than steel and concrete. Notable emissions savings are the result of substitution and sequestration benefits.¹
2. Mass timber can be an important structural material for reducing built environment embodied carbon emissions, but designers should not assume that all wood is equally good and considered the same.
3. Mass timber is sustainable only if forest management is sustainable. If carbon stocks are going up over time from a place producing timber, there may be a carbon sequestration benefit related to the wood produced there. Conversely, if carbon stocks are going down, there may be a carbon emissions burden.² Keeping forests as forests with matching productivity after harvest is important to maintaining the carbon benefit of timber products.
4. The influence of different forest owners and management approaches carry a much bigger impact than increasing efficiencies in transportation or manufacturing processes.² Thus, wood products certification and chain of custody are important for designers to feel confident in their material selection.
5. Wood growth and harvest is a relatively low-carbon activity, accounting for a small percentage of overall cradle-to-gate emissions associated with timber production.³
6. Processing and transport emissions associated with timber production may range from negligible to nearly equal to the amount of CO₂e stored in finished product.⁴ Products like CLT however, may generally be considered net negative carbon emitters because more carbon is stored in the product than is emitted to produce it.⁵
7. Wood drying and the use of adhesives in composite products are associated with high environmental burden.
8. Of the harvested tree, the stem and residues represent about 68% and 32% of the total biomass respectively.⁶ Stem-only harvest (using only the tree's bole, leaving residues and stumps on site) improves site remediation by benefiting biodiversity, soil carbon and nitrogen stock. Whole tree harvest utilizing excess fiber for long-lived wood products (e.g., mass timber, veneer lumber, wood insulation, mdf) is better for the climate than converting those fiber residues into short-lived products (e.g., paper, biofuels).

Timber Extraction to Building

1. Extraction

Before logs can be processed and turned into timber products, trees must first be managed and harvested. Ground based operations use feller-bunchers, skidders and processors to cut the trees at merchantable lengths. When trees are harvested, the tops and limbs are left as forest residues. These residues may be left behind to decay, piled and burned, or removed for use as bioenergy.⁷

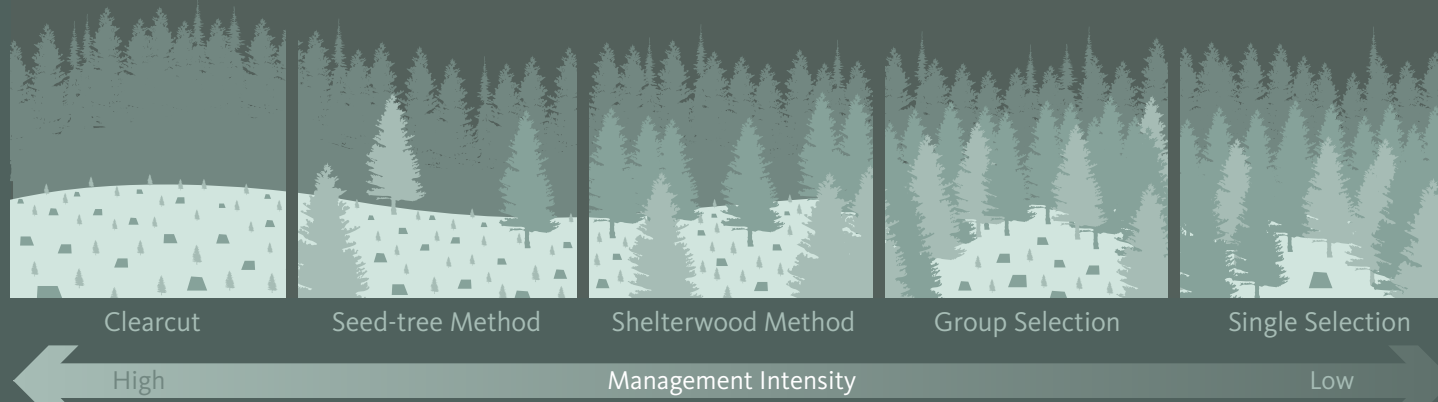
Once loaded onto trucks, the logs (aka roundwood) is transported to the mill log yard. Before entering the mill, roundwood is cut to lengths operable by mill equipment, sorted, and then soaked in log ponds or sprayed to prevent deformities before or during production. At the front-end of the sawmill, logs are then debarked for further processing into timber products.

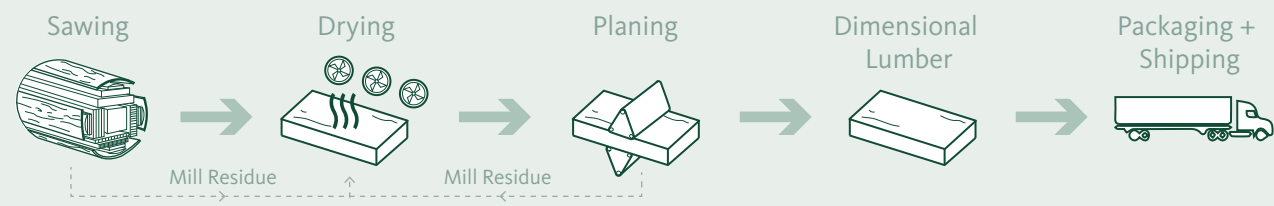


A Note on Forest Management

A variety of forest management strategies exist, all of which fall in line within a gradient of forest management intensity. Low intensity management prioritizes carbon

storage in forests while high intensity management prioritizes carbon storage in the built environment alongside substitution benefits

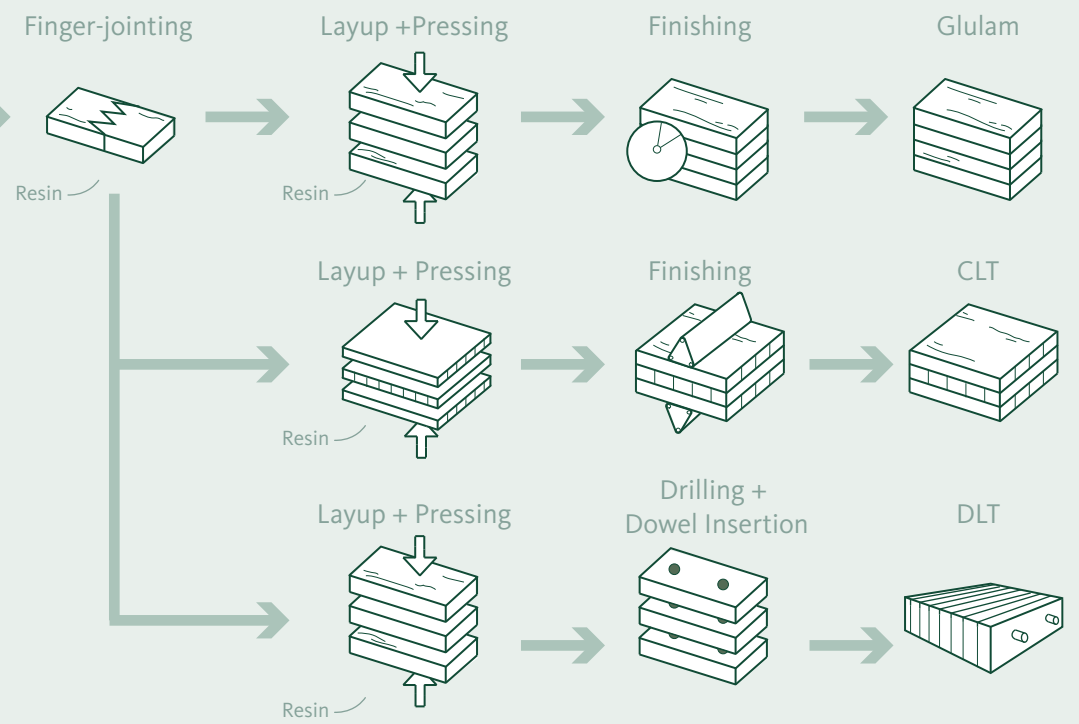




Production of Lumber and Lumber-Based Engineered Wood Products

After being debarked, roundwood is sent through a head rig to form green lumber. Cants and flitches may be resawn to form lumber. After sorting and stacking, green lumber is sent to the kiln for drying. Thermal energy is supplied by steam or through the combustion of woody biomass. Resulting dry lumber is then sent to the planer in-feed which involves unstacking, planing, grading, end trimming, sorting and packaging. Bark, chips, sawdust, and any other milling residues may be used as bioenergy to power mill equipment or may be sold as feedstock.⁸ Lumber is then shipped to a secondary facility for manufacturing engineered wood products.

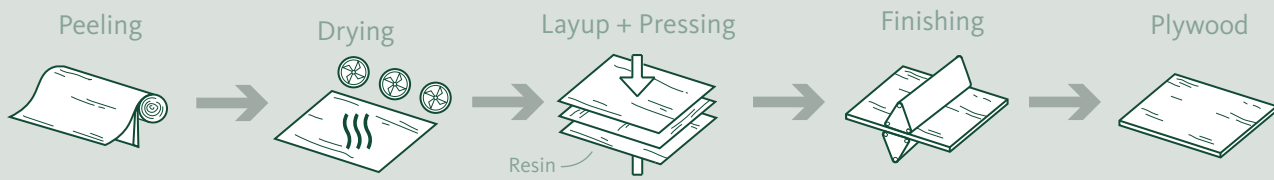
Glulam beams and CLT panels are typically manufactured in lengths longer than the lumber received from sawmills. To solve this, the ends of lamstock are finger-jointed so that lumber can be joined (with glue) from end-to-end. Curing systems using a combination of pressure and heat help to quickly stabilize the resin. Lamstock is then assembled specific to the required layup. Resin is applied to the face of each layer before the beam or panel is sent to the press. Once the resin has cured, all sides are planed down.⁹ Beams and panels are then prepared for shipping.



Glulam is a wood beam composed of wood laminations, bonded by adhesive, that run parallel with the length of the member.¹⁰

Cross Laminated Timber consists of several layers of kiln-dried lumber stacked orthogonally in alternating directions, bonded with structural adhesives, and pressed to form a solid panel.¹¹

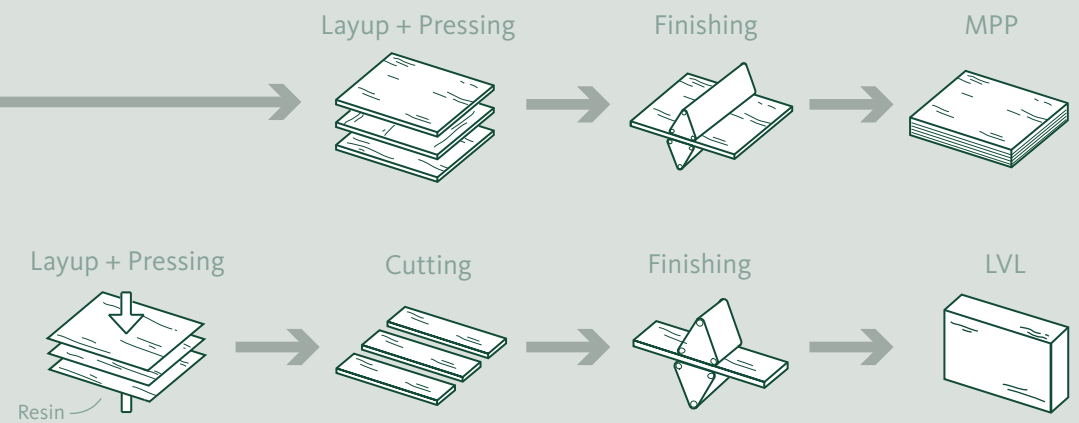
DLT is a panel made of standard dimensional lumber pieces friction-fit together on edge with wood dowels.¹²



Production of Veneer and Veneer-Based Engineered Wood Products

After being debarked, roundwood goes through rotary peeling. Veneers are dried and then placed into the layup sequence. For plywood, each layer is laid perpendicular to the next. In LVL manufacture, veneers run parallel to grain. Once resin is added to the face of each layer, the mats are assembled and pressed with heat/pressure. When

the resin has cured, mats and billets are sawn to desired dimensions and trimmed.¹³ The final products are plywood and LVL. The manufacture of MPP is a similar process to that of plywood, but formed with 1" lamellas made up of 1/8" veneers.



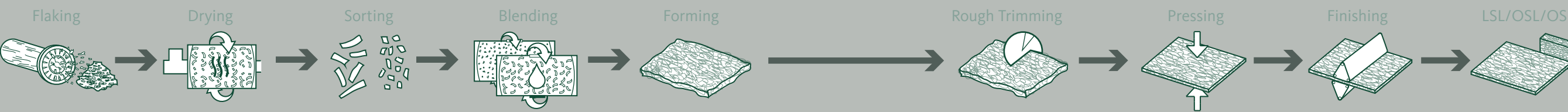
Mass Plywood Panel is a veneer-based panel assembled by combining stress-rated lamellas in both long and cross directions.¹⁴

Laminated veneer lumber is produced by bonding thin wood veneers together in a large billet so that the grain of all veneers is parallel to the long direction.¹⁵

Structural Composite Lumber (SCL) includes: LVL, PSL, OSL, and LSL



Parallel Strand Lumber is manufactured from veneers clipped into long strands laid parallel, and bonded together with an adhesive.¹⁵



Oriented Strand Lumber, Laminated Strand Lumber, and Oriented Strand Board are all made from flaked wood strands. OSB has cross-oriented layers while OSL/LSL have flakes running parallel.^{15,16}

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CARBON CONCRETE

Key Points about Concrete

1. Concrete is the most used building material worldwide,¹⁷ and can be produced from most locally available mineral resources. Concrete is also durable and long-lasting with important thermal benefits in some climates. 89% of concrete structures remain in service and are not demolished.
2. Cement and concrete manufacture are extractive processes. Approximately 1.5 ton of raw material is required to produce a ton of cement.¹⁸ Furthermore, concrete relies on the use of sand, the second most consumed resource on the planet after water,¹⁹ of which there is a global shortage. Extraction of these raw materials and aggregates creates ecosystem disturbances.²⁰
3. Portland cement (specifically clinker production) is responsible for approximately 8% of global GHG emissions, with one ton of cement producing approximately one ton of CO₂.^{21,22} Consensus in literature shows these emissions are the result of limestone calcination (60%) followed by high fuel consumption (40%). Reducing the amount of clinker is a key priority.
4. Supplementary cementitious materials (SCMs) are widely adopted and provide the most feasible means to reduce emissions associated with clinker production. One issue with SCMs is that they themselves may originate from carbon-intensive and polluting materials (e.g. fly-ash and slag). Additionally, further increases in substitution are limited by the reactivity and availability of conventional SCMs.²³ Ternary blends like limestone calcined clay cement (LC₃), however, are thought to be particularly promising.²⁴
5. Novel cements look to replace clinker entirely by introducing different raw materials that will emit less CO₂ and use less energy without compromising the quality of the cement.²⁵ Although new cements are under investigation, their implementation is hindered by the need for reformed building codes and design practices which will take more than a decade.²⁶
6. Recycled aggregate concrete (RAC) looks to conserve virgin resources by partially or completely replacing natural aggregate in concrete mixes with concrete construction and demolition waste, lending to environmental and economic benefit. It is generally reported that RAC properties degrade the more recycled aggregate is included,^{27,28} thus limiting its structural application.²⁹ However, some researches have successfully produced RAC with a performance that matched normal concrete.^{30,31}
7. Alternative fuels can modestly reduce emissions, as well as recover waste productively.
8. Since limestone calcination will likely stand a decarbonization challenge, carbon capture and storage (CCS) remains a key CO₂ abatement method for the cement industry.²³ CCS technology has strong recovery potential, but technical and economic barriers hinder their feasibility and large-scale deployment.³²
9. Carbon sequestered through carbonation may represent a significant carbon sink, potentially reabsorbing as much as 30% of cumulative CO₂ emissions from 2015 through 2100.³⁴ This carbon storage benefit may be outweighed by the long time needed for carbonation to sequester CO₂ which lags behind initial emissions on top of increasing cement production.
10. Building operational emissions are important. Changes to concrete production and the ways in which we design and maintain concrete structures (which improve building energy efficiency) can lead to more than 50% reductions in associated GHG emissions by 2050.³

Concrete: Extraction to Building

1. Extraction

Concrete is a cementitious material formed by combining cement, water, and aggregates.

Cement is the key ingredient within concrete that serves as a binding agent. A majority of concrete's carbon emissions revolve around cement production.

Raw materials needed for cement production can be divided into 4 categories: Lime, Silica, Aluminum, and Iron Oxides. Limestone is the main ingredient and provides the lime, while clays (including shales, slates and marls) provide the silica, alumina and iron. In Portland cement, limestone and clays make up about 80% and 20% of the mixture respectively.²⁵ These materials are quarried at surface mines which are often close to the cement plant.³⁶



Sand and Gravel

After water, sand is the most consumed resource in the world and is mostly driven by concrete demand, with sand making up about two-thirds of its composition.³⁷ Since sand is a product of rock erosion over thousands of years, its increased exploitation exceeds its rate of renewal, leading to shortages of the finite material.^{38,39} Shortages exist because concrete production often requires water-

eroded sand where rough angular grains hold stronger structural integrity compared to wind-eroded sands, (like deserts), where grains are too smooth.¹⁹ Besides potential resource depletion, the effects of sand mining are widespread and may extend beyond the mining site as evident by ecosystem degradation, loss of biodiversity, and risks to community livelihoods.

Sand mining negatively affects communities and the environment in a number of ways^{20,40}

Water

- Increased water turbidity
- Increased soil and coastal erosion
- Reduced water quality and pollution
- Deformation of riverbeds and banks
- Changes in water flow and flood regulation

Communities

- Reduced protection to extreme events
- Reduced productivity of agricultural land due to lower water tables
- Damage to local infrastructure due to instability of soil erosion
- Reduced drinking water quality

Air

- Increased air pollution

Land/Soil

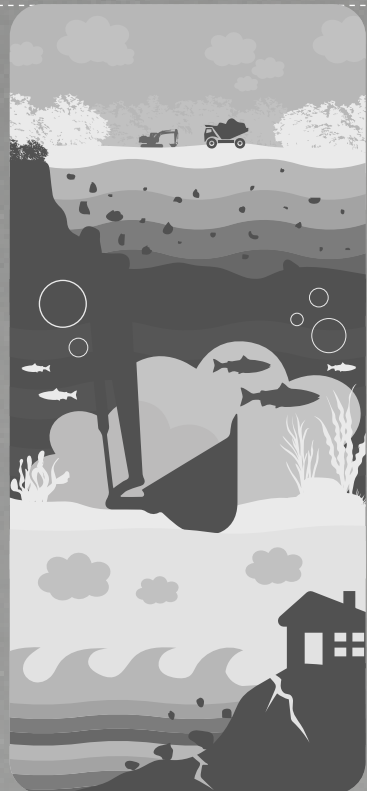
- Decreased soil quality
- Soil Erosion
- Landscape disturbance

Biodiversity

- Habitat loss
- Altered number of animal species
- Destroyed vegetation

Carbon

- Sand mining in riparian areas releases soil carbon, reduces carbon sequestration potential and impacts nutrient cycling.⁴¹



Riparian forestland, river and lake beds, soil and river deposits



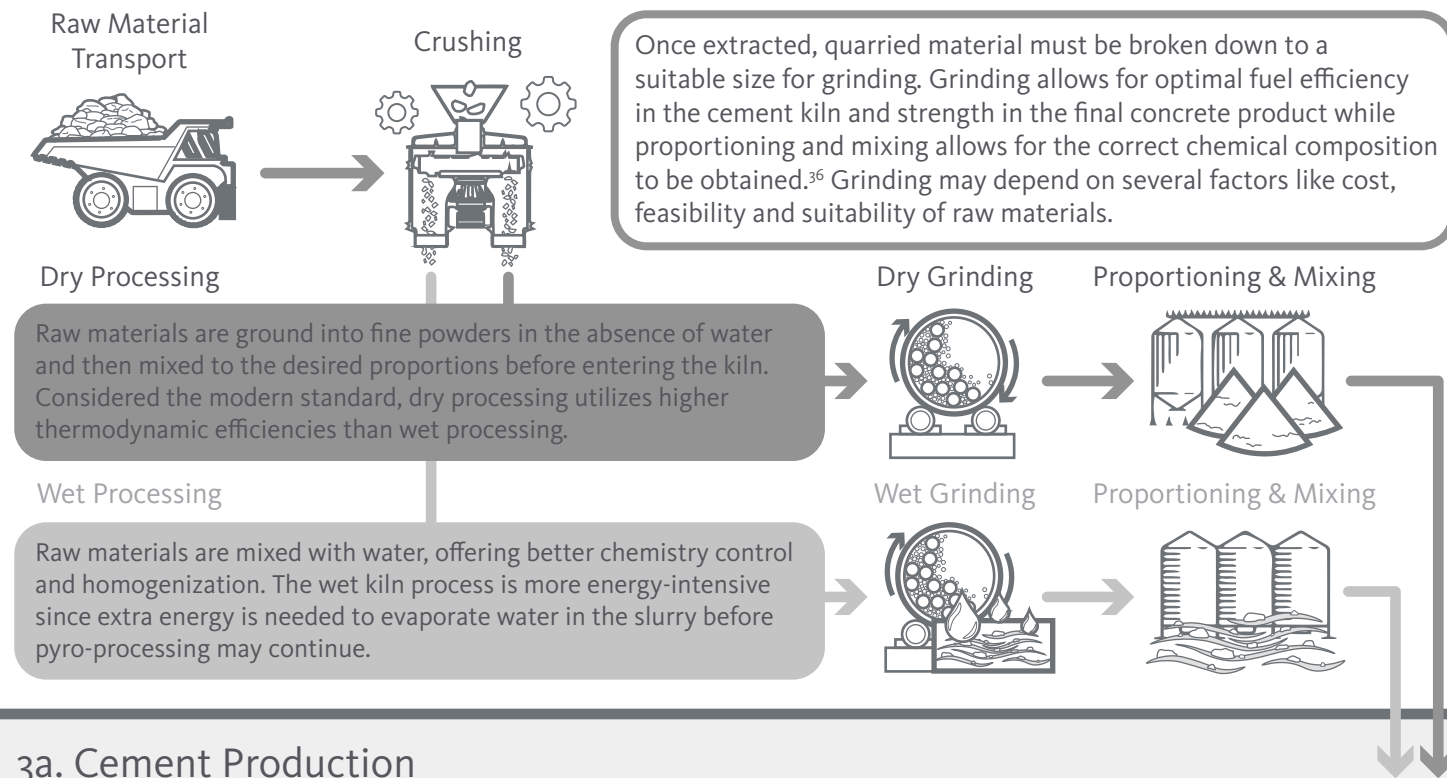
Coastal and marine environments



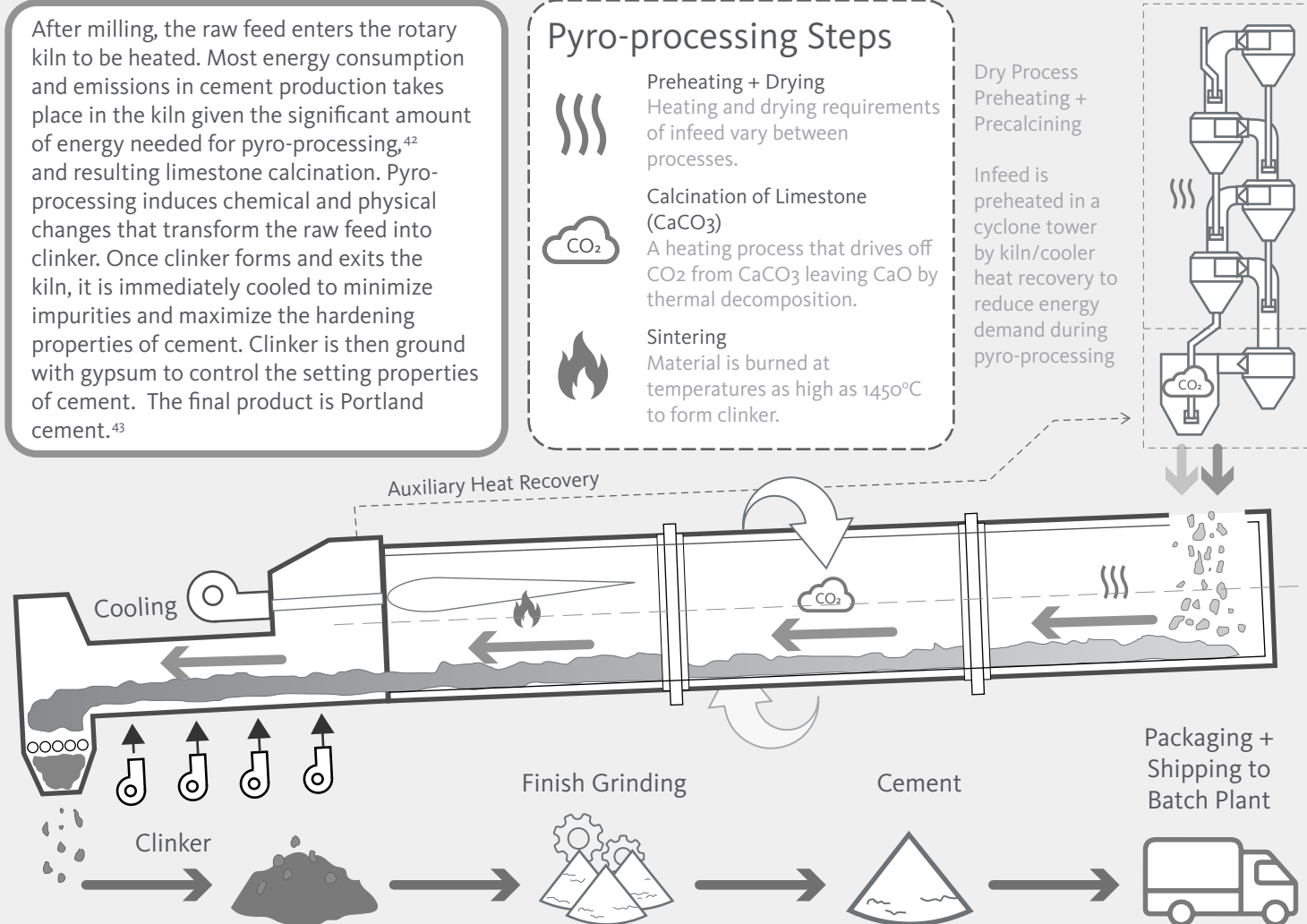
Sand dunes, volcanic material, dried lake beds, and quarries



2. Cement Raw Material Preparation



3a. Cement Production



3b. Supplementary Cementitious Materials (SCMs)

SCMs generally include industrial waste or other materials that possess pozzolanic properties. Since clinker is related to high fuel consumption and limestone calcination, its partial substitution with SCM's remains a key priority.²² Their inclusion can produce quality blended cements, although each changes the cement's performance different or even limiting properties compared to ordinary Portland cement,²⁴ including strength development over time.³² The limited availability and reactivity of classic SCMs remain a big challenge.



Fly-Ash, by-product of coal combustion

Fly-ash is relatively available but its quality is highly variable with less than a third of it suitable for blending in cement. Its low reactivity limits the extent of clinker substitution compared to slag.²⁵⁻⁴⁵



Limestone is abundantly available

Since limestone is used for clinker production, its availability is often close to cement plants. Commonly used as a filler, limestone is ground into fine particles, and more easily than grinding clinker.⁴³ Substitution rates are often low to limit poorer mix properties.



Blast-Furnace Slag, by-product of steel production

Slag can replace a substantial amount of clinker however its availability is limited since steel demand is not as rapid or widespread as it is for concrete. Slag's availability is further limited since more steel is being recycled than produced from virgin material.²⁵⁻⁴⁵



Natural Pozzolans, and Clays are widely available in natural deposits

Limestone calcined clay cement (LC₃) not only can reduce clinker by as much as 40-50%, yielding lower overall emissions and strengths comparable to traditional Portland cement,³¹ but is also thought to be a promising blended cement.²⁵⁻⁴⁵

3c. Alternative Fuels

Alternative fuels cover all non-fossil fuels and waste from other industries. Substituting fossil fuels with alternative fuels not only lowers fossil fuel emissions, but also conserves natural resources, lessens the environmental impact associated with mining, and recovers waste productively.⁴²

One limitation to alternative fuel sources is that the burning behavior of most alternative fuels differs from traditional fossil fuels. Different burning profiles can change the firing performance of kilns (including the sintering temperature, length of the sintering zone, and cooling conditions) and may influence clinker properties. Another important limitation is the potential inclusion of combustion by-products that may be locked-in and contaminate clinker quality.⁴⁵

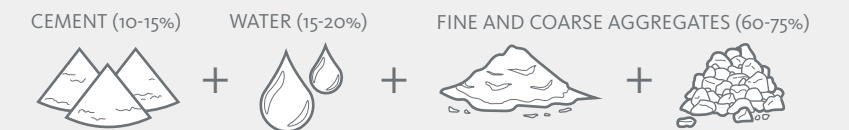


Important considerations for alternative fuels:

- moisture content
- calorific value
- emissions released
- toxicity
- content of VOCs
- cost
- availability
- physical state of the fuel (solid, liquid, gas)
- physical properties (size and density)
- grinding properties
- content of circulating elements

4. Concrete

Once it arrives at a concrete batch plant, cement is combined with water and aggregates. When water combines with cement, a chemical reaction called hydration occurs, forming a paste, or "glue", that binds aggregates together and gives concrete its strength.



Cement makes up about 10-15% of concrete's composition but accounts for 74-81% of total emissions. The next largest source of emissions are coarse aggregates at 13-20% of total emissions, with about 80% of those emissions coming from crushing materials. The production of fine aggregates generates less emissions because they are only graded, not crushed.⁴⁶

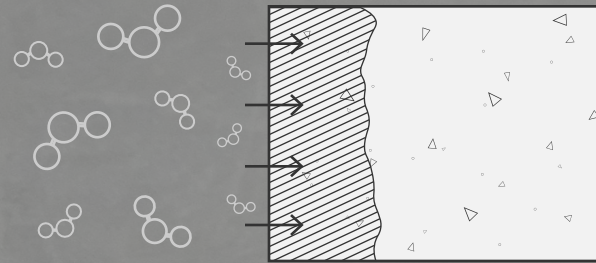
Carbonation

To understand the full scope of cement's net emissions and role in the global carbon cycle, it is important to address carbonation, the mechanism by which atmospheric CO₂ reacts and bonds with hydrated cement in concrete. The

process essentially works in reverse of limestone calcination (i.e. decarbonization) where cement's maximum exposure to air allows for gradual re-absorption of carbon over time.

Decarbonation
 $\text{CaCO}_3 = \text{CaO} + \text{CO}_2$

Carbonation
 $\text{CaO} + \text{CO}_2 = \text{CaCO}_3$

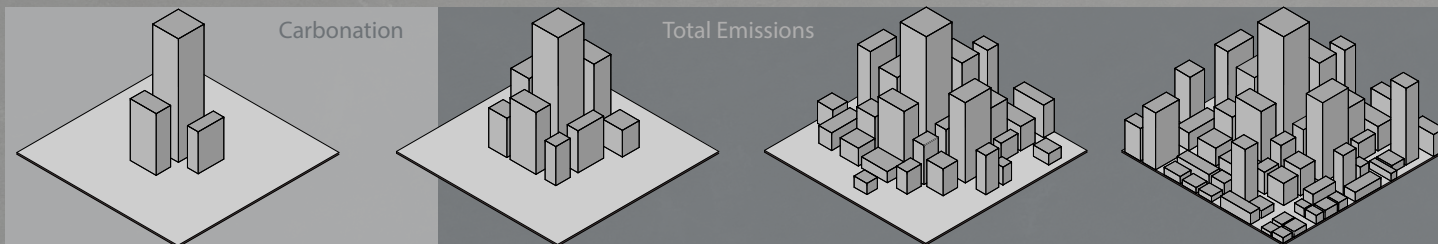


Calcite products fill the micro structure through diffusion, with a rate that decreases as carbonation increases. Surface-to-volume ratio, moisture content, porosity, and ambient conditions are some factors that affect the quantity and rate at which carbonation takes place.

Cementitious materials like concrete sequester a non-trivial amount of CO₂ through carbonation and may leave opportunities to create sustainable end-of-life pathways for the cement and concrete industries.

Carbonation has generally been studied for its negative impact on durability, particularly regarding the corrosion of steel components in reinforced concrete, but increasing pressure to decarbonize has renewed attention on the environmental benefits of carbonation.⁴⁷ Most studies that report on concrete embodied carbon often exclude carbonation since cement and concrete remain large net emitters of CO₂ even when carbonation is considered.⁴⁸ Still, numerous other studies show that carbonation may

reabsorb a serious, but varying, range of initial emissions and that LCA's excluding carbonation may be overestimating concrete emissions by as much as 20%.^{21,49} As new construction is projected to increase (likely out of concrete), the significance of carbonation may increase as cement stocks continue to grow.³⁴ Furthermore, since CO₂ captured by carbonation is permanent (unless re-burned), concrete can be considered a long-term engineered carbon sink.⁵⁰



Ultimately, carbonation alone will not be enough to meet climate goals as rapid decarbonization must be accompanied by extreme measures that incorporate other innovative technology.³⁴

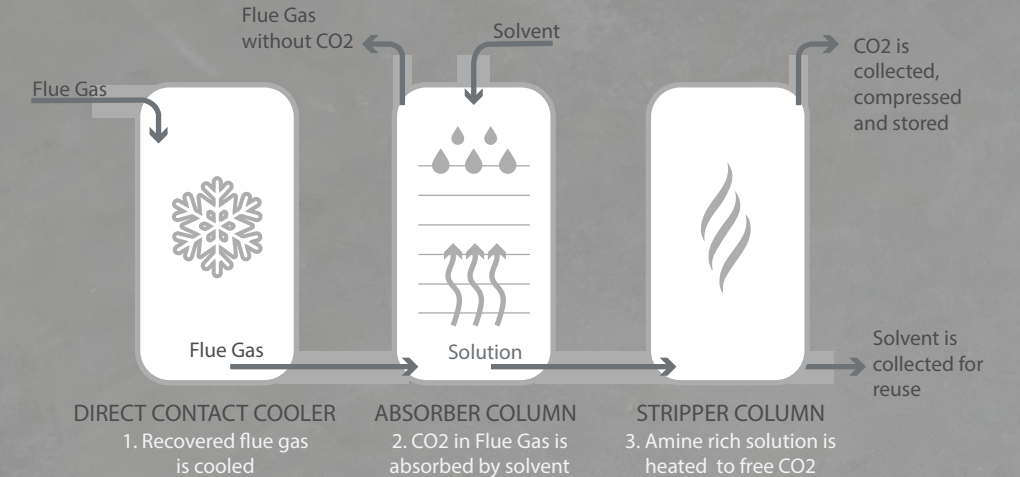
Natural (aka passive) carbonation occurs slowly over a long period of time with most of the carbon benefit occurring at concrete's end-of-life. While the cumulative benefit gained from carbonation is significant, ultimately only a fraction of total initial emissions from concrete production are re-captured. Consequently, carbonation lags behind emissions and may be less substantial for new buildings. Research into technology utilizing active carbonation methods which seek

to accelerate the reaction of cement in various phases of concrete's life cycle, further expands opportunity for more viable short-term strategies.⁵¹ Lastly, as blended cements remain the most feasible solution to decarbonize the industry, it should be noted that carbonation rates through concrete containing SCMs differ from that of normal concrete utilizing ordinary Portland cement.⁵²

Carbon Capture and Storage (CCS)

CCS technology does not reduce CO₂ emissions, but merely separates, stores, and prevents CO₂ from being released.³³ Although CCS technology has not reached commercial scale deployment, it will become an unavoidable necessity if rapid decarbonization of the concrete industry is to meet climate goals.^{23,53} CCS technology is generally categorized as either pre-combustion, post-combustion, or oxy-fuel combustion. Since pre-combustion technology deals with energy-related emissions, and most emissions associated with cement production occur in the kiln due to limestone calcination,

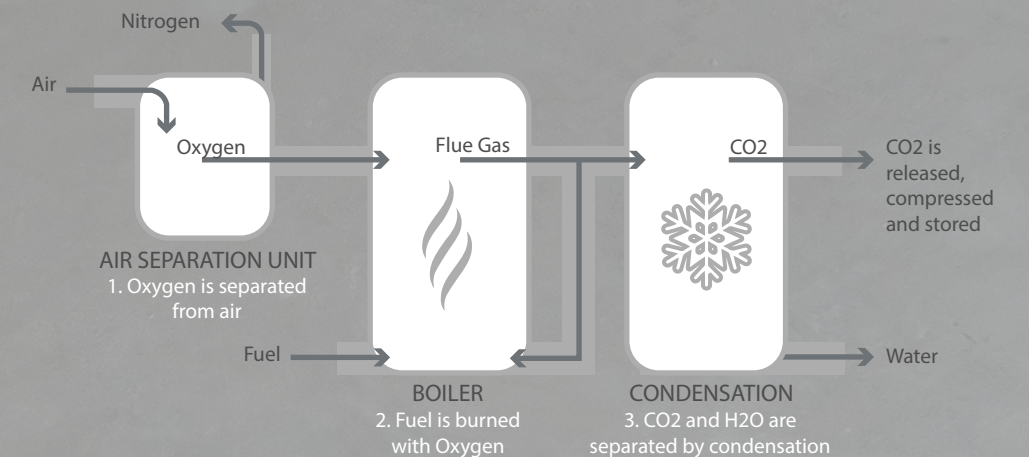
pre-combustion technologies have limited potential in the cement industry. As a result, post-combustion and oxy-fuel technologies are more often discussed. Unfortunately, CCS is met with technical and economic hurdles, including costs for implementing new infrastructure and significant energy demand needed to operate the technology.



Post-Combustion CCS (Chemical Absorption)

Post-combustion capture involves CO₂ sequestration from flue gas after fuels have burned. Because of their "end-of-pipe" characteristics, post-combustion are the most feasible implementation of CCS technology as they can be applied to new and existing plant installations.³² Among the many different post-combustion technologies being investigated, the most promising is through chemical absorption as it already exists in several industries, is proven to capture CO₂

from the calcination process, and can achieve high abatement efficiencies. Its main disadvantage is high energy demand, particularly with heating and regenerating the amine rich solvent.³² Since modern cement plants already operate at high thermodynamic efficiencies with little more room for improvement,⁵⁵ waste heat recovery becomes less of an option as it is already used to supply the kiln and precalciner.⁵³



Oxyfuel Combustion CCS

Although its implementation is expected to take longer than that of post-combustion and it is still in its infancy, oxy-fuel combustion is one other CCS strategy capable of high emission reductions in cement operations. This technology relies on pure or nearly pure oxygen instead of ambient air to burn fuel, producing flue gas with a high concentration of CO₂.

In the absence of nitrogen (which makes up 79% of air), fuel consumption is reduced since there is no nitrogen to burn.⁵⁶ A couple of advantages include improved fuel efficiency and clinker throughput while disadvantages include energy penalties from the air separation unit as well as the need for major re-modification of the entire cement plant.⁴³

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CARBON STEEL

Key Points about Steel

1. Steel is produced chiefly from iron ore, the fourth most abundant material making up 5% of the earth's crust; its extraction carries significant environmental burden including land transformation, contamination to air and soils, as well as waste generation (e.g., effluent emissions).⁵⁷ Eco-toxicity impacts throughout the steel production chain have serious consequences.⁵⁸
2. Identifying reducing agents in iron making is a key priority for the decarbonization of the steel industry.⁵⁹ The burning of coke for iron ore reduction is at the core of the steel industry's emissions.^{26,60}
3. Hydrogen as a reducing agent is thought to play a crucial role in the decarbonization of the steel industry with the potential for significant deployment by 2030.⁶¹ The success of hydrogen as a clean energy carrier will depend on how it is produced, as well as the cost and feasibility of upscaling infrastructure needed for its storage and transport.
4. Responsible for about 7% of global CO₂ emissions,⁶¹ steel is produced via two main routes: the blast furnace-basic oxygen furnace (BF-BOF) route and electric arc furnace (EAF) route. Emissions and energy consumption are the largest for the BF-BOF route,⁶³ which accounts for about three quarters of global steel production. The most efficient BF-BOF systems produce ~1.8 tonnes of CO₂e per tonne of steel produced although the global average is closer to 2.3 tonnes of CO₂e.^{64,65} Steel produced through the EAF, which accounts for the remaining quarter of global steel production, can achieve ~0.2-0.5 metric tons of CO₂e per tonne of steel produced.⁶⁶
5. Direct reduced iron (DRI) represents ~5% of global steel production. The current DRI-EAF route which predominantly uses natural gas, has only 61% the carbon footprint of a traditional integrated BF-BOF route. When fueled by hydrogen, the DRI-EAF route can achieve reductions close to net-zero.^{26,66}
6. Like the cement industry, carbon capture, utilization and storage (CCUS) is an essential, but under-utilized, technology that plays an important role in reducing emissions. Unlike the cement industry which only has one main point source (the kiln), steel plants have multiple.⁶⁷
7. Increased recycling is another key priority to reduce the steel industry's emissions. Steel has seemingly infinite recycling possibility and strongly developed end-of-life markets. The greatest limitation to steel recycling, and therefore the use of EAFs, is that most steel is locked away in current uses.⁶⁸ Virgin ore must therefore be extracted and processed to keep up with demand.
8. Steel scrap quality degrades over time with the accrual of impurities, making re-processing difficult each cycle. Although currently diluted by iron, the accumulation of copper is expected to become problematic and may potentially impede future recycling.⁶⁹ Improved sorting and recovery of steel scrap can help increase recycling and slow the increase of residuals.
9. Breakthrough low-carbon technologies require big upfront capital investments, likely followed by higher operating costs.⁶⁴ As a result, green steel may initially be more expensive than conventional steel, and its adoption limited without government procurement.⁷⁰
10. Mature strategies such as material efficiency, increasing share of recycled scrap, optimization of energy-saving technologies, DRI, CCUS, and various forms of fuel-switching will produce the most effective emissions savings in the near-term.⁶¹

Steel: Extraction to Building

1a. Extraction of Raw Material

Steel originates from iron ore which is often extracted from surface mines. Crushing is the first step of ore processing, and occurs in several stages. Ore is then transferred to refining facilities (usually located on site) where it is beneficiated to seek out desired minerals. Where crushing is

usually a dry process, grinding is performed wet to provide a slurry feed to the chemical concentration process.⁷¹ The greatest share of energy consumption and environmental impact are associated with the process of grinding down iron ore to extract impurities.

High-grade ores sought after to produce high quality steel are now harder to come by because of resource depletion. Lower-grade ores are more intensive to manufacture.⁷²



1b. Recycling of Scrap Material

The greatest limiting factor for recycling steel is the insufficient availability of scrap steel.⁶⁸

Steel's longevity and seemingly infinite recyclability while retaining key properties create great opportunities for closing material loops, reducing embodied carbon, and conserving virgin material. However, since most steel is locked away in current anthropogenic uses, industry is compelled to continue mining virgin iron ore.

Steel Scrap Quantity

Where steel scrap is available, it may come from a variety of sources⁷³:

Home Scrap

Scrap that is a by-product within the production process and never leaves the steel mill.



New Scrap

New scrap is generated in steel product manufacturing plants and is generally returned directly to the mill within weeks or months.



Old Scrap

Old scrap is steel that has served its purpose at the end-of-life of a product. This category produces the largest share of recyclable steel and may come from a variety of sources including demolished buildings, old vehicles, appliances, and other worn-out steel products.



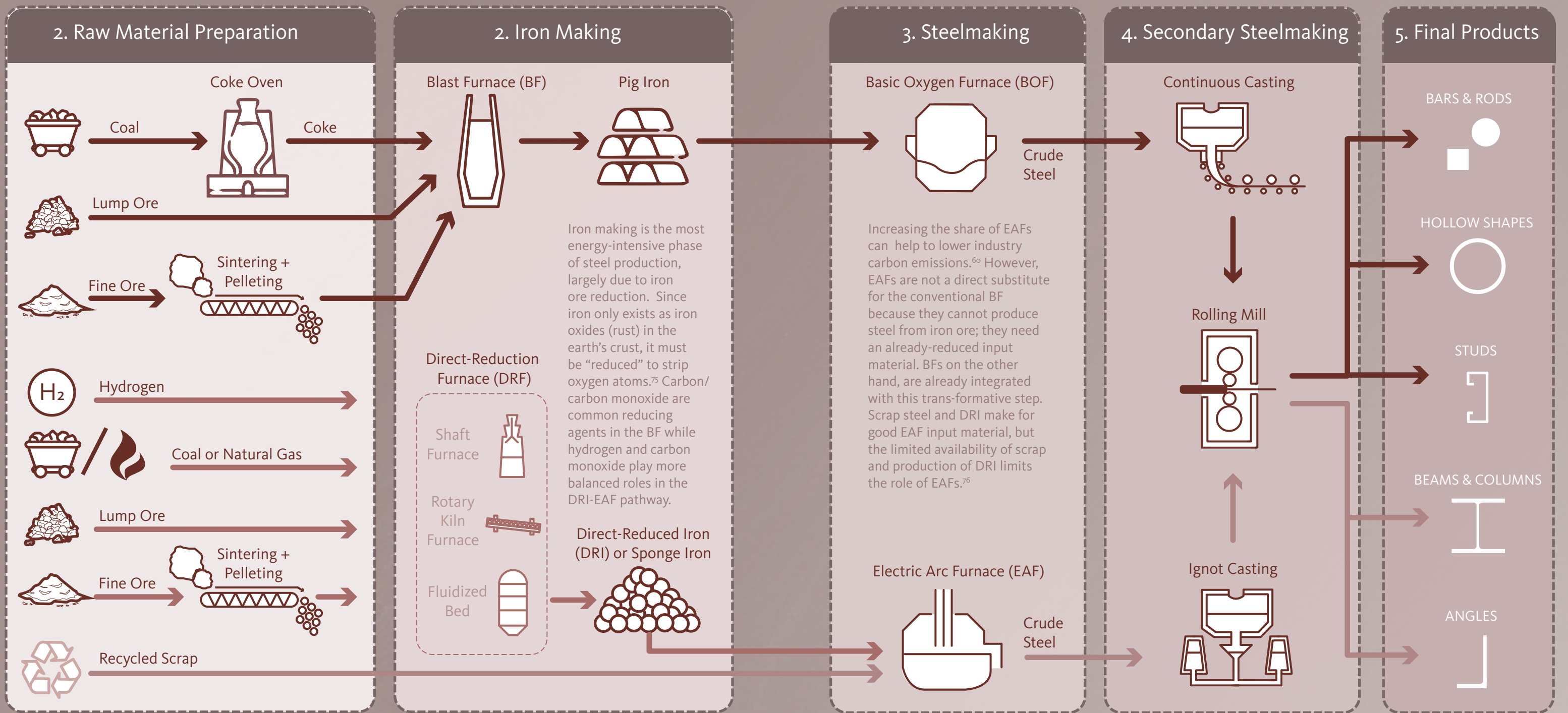
Steel Scrap Quality

Steel quality is highly influenced by scrap input, with differences in scrap quality defined by the different alloys used in the steel making process, coatings applied, and treatments after collection. Every time steel is re-circulated, the concentration of residuals increases making reprocessing of scrap material more difficult. These residuals often include alloying elements such as copper, tin, nickel.



High-quality scrap demands less energy to process than low-quality scrap. Since secondary steel making with low-quality scrap is still environmentally better than the primary production of steel with virgin material, any form of scrap grade should be accepted into the EAF. Improved recovery can help to increase recycling which is needed to reduce steel industry emissions.⁶⁹





After mining and beneficiation, crushed ore from the mining site, called lump ore, is sent to the BF-BOF or DRF. If lump ore is too small for processing, fines are must be enlarged. Agglomeration of fines into sinter or pellets requires heat and pressure, consuming varying amounts of fossil fuels and electricity.⁶¹

Some recycled scrap is inputted into the BF-BOF (usually <30%), but scrap is generally send directly to the EAF. Due to how scrap is found and gathered, a variety of scrap grades exist. To increase recycling and slow the accrual of residuals, improved sorting is needed but not yet economical.⁷⁴

The primary method for steel production, is the BF-BOF route. Iron ore reduction takes place in the BF, where ore is heated with coke as the reducing agent and liquefied. Because the iron is soft and can re-corrode with oxygen, alloying elements are added in the BOF to produce steel with desired qualities. The BF-BOF pathway is the most energy-intensive way to make steel and its decarbonization potential is limited.⁷⁴ Top-gas recycling of off-gases, conversion of off-gases to fuels/chemicals, and deployment of CCUS are some technologies capable of reducing BF emissions.⁶¹

The second route to reduce iron ore is through direct reduction in DRFs which chemically remove oxygen from iron ore in its solid state (skipping liquification). The result is sponge iron which is then sent to an EAF. Electricity is used in the EAF to heat the metal and produce crude steel. DRFs do not need coke and are significantly less energy-intensive than the BF-BOF method.⁶⁶

The EAF is the most common way of producing secondary steel from recycled steel scrap. There is not enough recycled steel to meet growing demand using the EAF method alone, but the combined DRI-EAF route has the greatest decarbonization potential. Using natural gas, the DRI-EAF route has a carbon footprint thats approx. 61% of steel emissions produced in the BF-BOF. If only hydrogen were used, it can be close to zero emisisions.²⁶

Finally, crude steel goes through casting into slabs, blooms, or billets which are hot-rolled or cold-rolled into desired shapes. Typically, hot-rolled steel originates from EAFs while cold-rolled steel typically uses BF-BOF pathways.

Hydrogen

Hydrogen is the most abundant element in our universe, and on earth exists in large quantities as water. Hydrogen will likely play an important role as a clean energy carrier for transitioning to net zero emissions, especially for hard-to-decarbonize industries (iron and steel production) where direct electrification will be difficult to implement.⁷⁷ Of the 94 million tonnes (Mt) of H₂ produced globally in 2021, 5 Mt was consumed by the DRI process in steelmaking.⁷⁸ The DRI-EAF with hydrogen as a reducing agent in steel production is a viable alternative to the conventional BF-BOF process capable of substantial emissions savings,⁷⁹ given the system's lower energy intensity and greater flexibility towards "hydrogen-readiness".

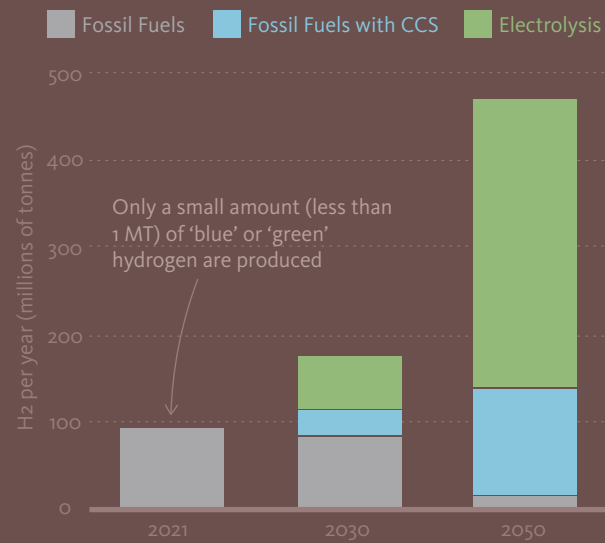
Hydrogen comes from the Greek words "hydro" and "genes" meaning water forming. When hydrogen burns with oxygen it "creates water".⁸⁰

Hydrogen will become an important climate change mitigation strategy for the steel industry to decarbonize and may even see a five-fold increase in production by mid-century.

Colors have been dubbed as a way to differentiate the way hydrogen is produced. Grey hydrogen is produced from unabated fossil fuels. Blue hydrogen is produced from fossil fuels accompanied by CCS. And green hydrogen is produced by combining renewable energy with water electrolysis.⁸¹

Virtually all hydrogen currently used in the industry sector comes from unabated natural gas and coal, leading to 630 Mt of direct CO₂ emissions in 2021. These direct CO₂ emissions can be considerably reduced by applying CCUS.⁷⁸ Blue hydrogen produced from gas reforming and coal gasification are mature technologies, but these routes do not represent a long-term mitigation strategy due to continued dependence on fossil fuels and potential carbon emissions. Fuel blending can serve as a transitional effort to alleviate dependence on carbon as a reducing agent, and will likely constitute a large portion of hydrogen production in the future. Displacing natural gas in DRFs and coal injection in BFs is already possible, but technical process constraints limit the amount of blending that can occur without equipment modification, particularly for BFs which have a minimum coke requirement for operation.⁷⁷

Hydrogen Sources



Projections in IEAs net zero emissions scenario.⁷⁷ Graphic adapted from Castelvecchi, Davide. 2022.⁷⁵

The environmental impact of hydrogen will depend on how it is produced.

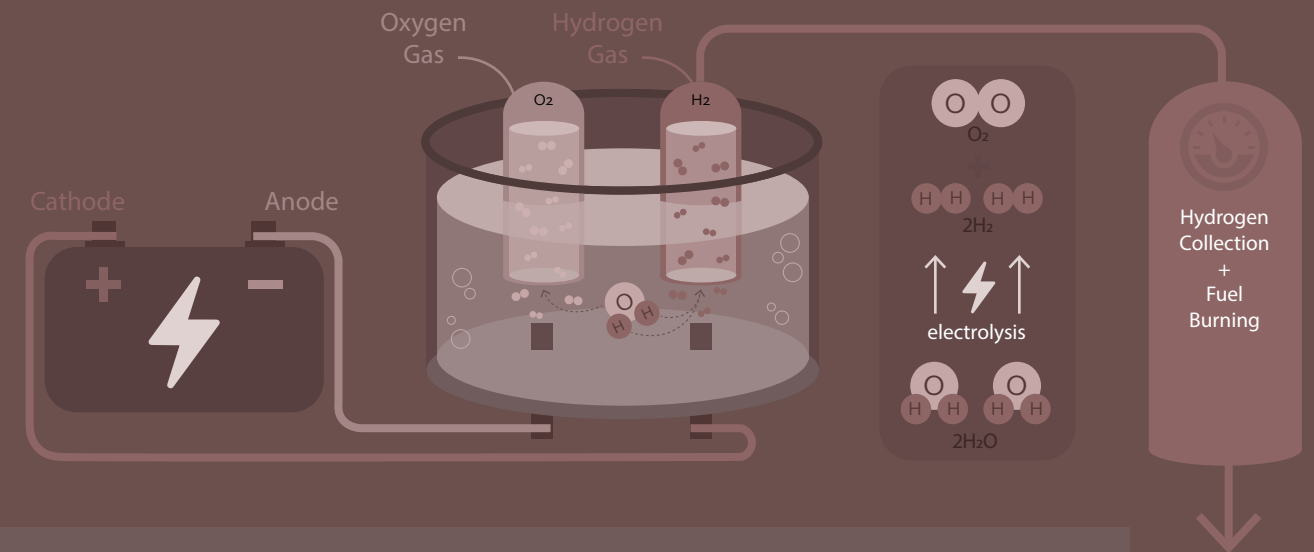
A strong effort should be made to produce low-hydrogen (such as green hydrogen generated from renewables and electrolyzers) but its production will depend on the availability and cost of renewable energy. Although currently greater than that of fossil fuels and hydrogen derived from them, the cost of renewables should decrease

with their greater deployment.⁷⁷ However, since renewable energy can fluctuate daily or seasonally, a stable supply of renewable energy will be important for hydrogen production. Solar and wind can power hydrogen production at low costs and high load factors when combined or coupled with storage.⁷⁸

Water electrolysis, which uses an electric current to separate hydrogen from oxygen in water, shows significant potential for producing low-hydrogen in steel production.

As the market for electrolyzers and the number of planned electrolyzer projects see significant growth, rapid scale-up and commercial deployment of electrolysis is expected by 2030. Global electrolyzer capacity could exceed 134 gigawatts (GW) by 2030 with an increase of electrolyzers reducing their capital costs significantly.⁷⁸ Low-hydrogen

produced from electrolysis can be used to supply hydrogen-ready DRF's in steel production. Since electrolysis produces no CO₂, it could theoretically be zero-carbon, but only if the electricity needed to power the process is generated without causing emissions.⁸²



Aside from how hydrogen is produced, the success of hydrogen as a clean fuel will also depend on its feasibility of scaling up. Strategic and cost-efficient planning will be needed to develop adequate infrastructure for a hydrogen network.

Hydrogen is currently produced close to where it is used and will likely remain near industrial facilities in the short term. As both production volumes and transport distances expand to meet increasing demand, more hydrogen infrastructure will be needed.⁷⁸

Hydrogen is transmitted through pipelines similar to how natural gas is today. Constructing new pipelines would bring costly upfront investments; fortunately, existing natural gas infrastructure can be re-purposed to fast-track hydrogen's development in the energy system and bring substantial cost-benefits (cutting investment costs 50-80% relative to new pipelines). Blending hydrogen into natural gas streams using existing infrastructure can serve as a transitional strategy to kick-start hydrogen production until the market grows enough to justify re-purposing existing pipelines or building new ones.⁷⁸

Adequate infrastructure for hydrogen storage is critical to ensure a reliable supply but it presents a great challenge. Being the lightest of all the elements with very low volumetric energy intensity, hydrogen takes up a significant amount of space. Large-scale hydrogen storage in salt caverns is already used at a commercial scale, however this approach is limited by region due to varying geological conditions. Alternative storage methods such as in other geological formations, physical storage (compressed hydrogen gas and liquefied hydrogen), adsorption, and chemical storage, still need further research and advancement.⁸³

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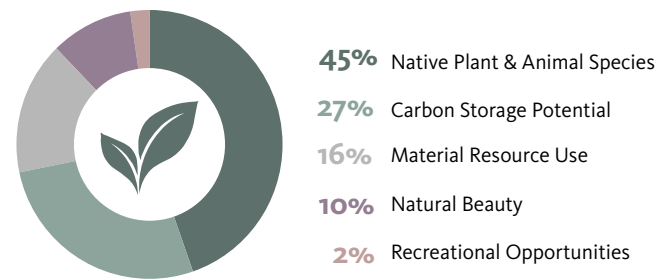
Survey

To begin this project, we sent an anonymous survey to architects, engineers, contractors, non-profits, academics, manufacturers and government representatives across North America to see what these groups value about forests and also help frame unanswered, confusing or conflicting narratives about carbon in structural building

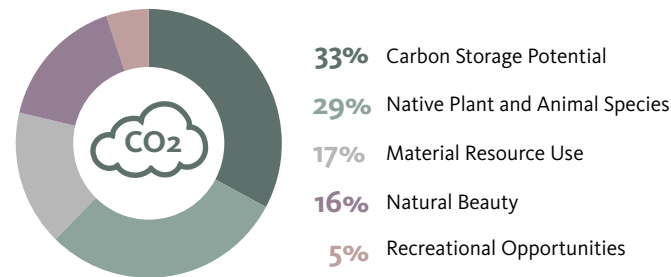
materials. We received 305 responses, 180 of which were from the AEC community. Below are the responses to the multiple choice and open-ended survey questions. The responses provided by the AEC community framed the workshop topics and invited speakers.

“Please indicate the importance you place on the following considerations for the use of forested lands.”

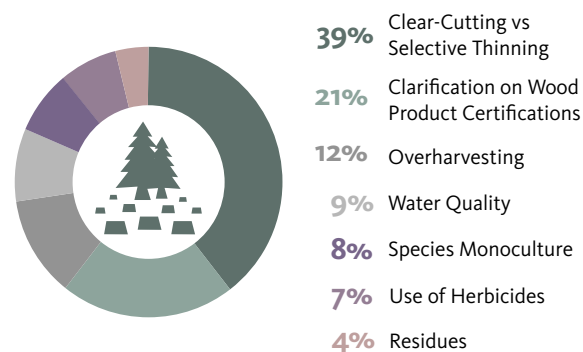
Most important



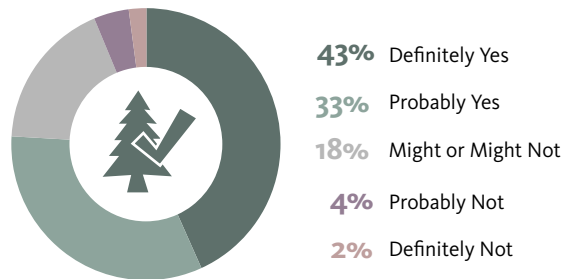
Second most important



“Regarding forestry practices in your region, what topics would you want more information about?”



“Is the certification of wood products an important consideration for your selection and specification?”



Certification can be a cost burden

“FSC is preferred because the available data shows that it improves chance that there is a net carbon benefit (Diaz 2018). However, clients tend not to select because of the cost premium (10-15%). Need data on SFI and PEFC to judge their impact. We specify SFI as our baseline because there is no cost premium in the pacific northwest, and we presume it has some carbon improvement over state forest practice laws.”

Architecture, works in the Southeast, West, and Northwest US

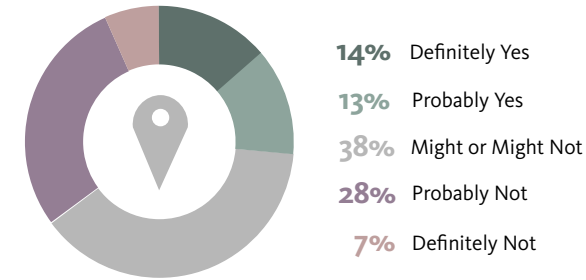
“I wish that the certification was a higher priority but when it comes time for budget reconciliation, if the certified materials add significant cost it does not always hold on as a high priority item.”

Architecture, works in the Northwest US

“I prefer to specify the highest environmental quality that the owner will allow/afford.”

Engineering, works in the Midwest, West, and Northwest US

“When considering the carbon impacts of (wood) fiber sourcing, does locality matter more than forest management practices?”



“From your perspective, what topics regarding structural materials’ manufacture, and construction methods would be most beneficial for designers and policy makers to understand?”

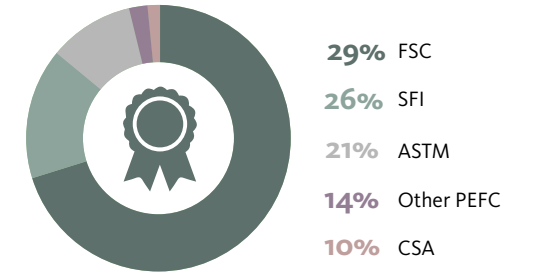
“If we are to use wood, we need a clear consensus that it is an environmental improvement over other materials. Ways to reduce end of life impacts are also critical as are forestry practices and how climate change is impacting forestry.”

Architecture, works in the West and Northwest US

“embodied carbon, habitat impacts, overall sustainability of resource, impacts on local economy and jobs”

Architecture, works in the West and Northwest US

Which certification do you prefer?



“FSC because people are more familiar with it.”
Architecture, Northwest US

“They are all good at different things - currently I believe SFI and FSC are ALMOST at the same level depending on where in the country you live (IE - Southeast)”

Architecture, works all around the country and abroad

“FSC, most easily sourced.”

Construction/Developer, Northwest US

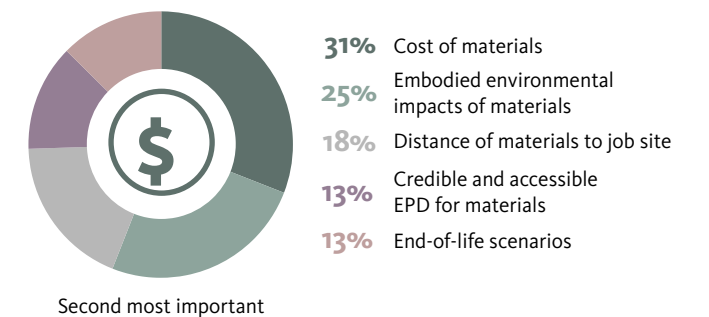
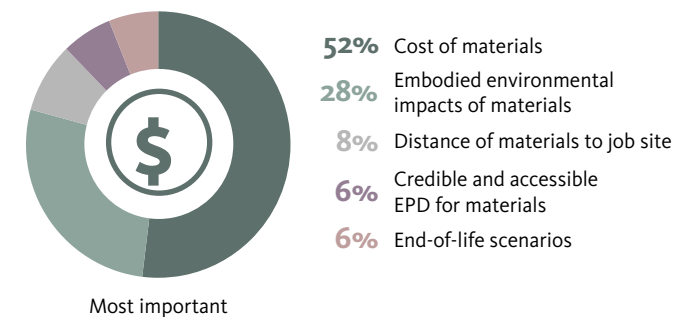
“FSC. Seems more legitimate than the industry-controlled SFI”

Architecture, Northwest US

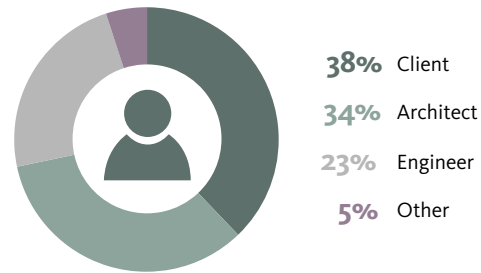
“FSC is the certification I am most familiar with. Have not had experience with the other two.”

Architecture, Northwest US

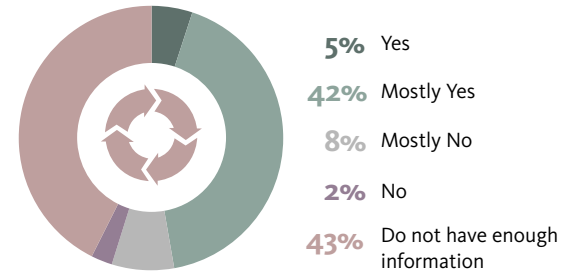
“Please indicate the importance you place on the following considerations when selecting structural systems.”



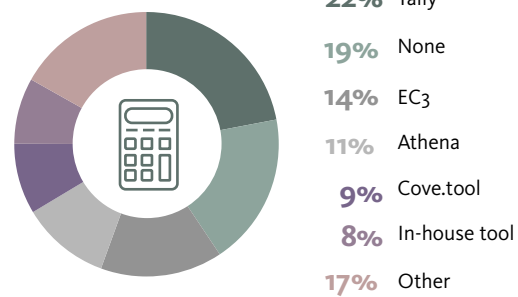
“Who often makes the final decision on a project’s structural system material?”



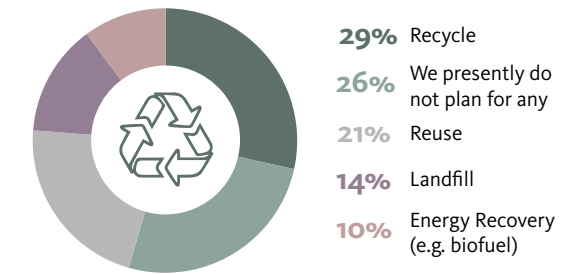
“For the life cycle assessment (LCA) tools that you use, are you comfortable with the assumptions made in the calculations?”



“What tools do you use to analyze the carbon impacts of your design projects?”



“Which end-of-life scenarios does your practice plan for with regards to structural materials?”



“What assumptions should be included in life cycle assessment (LCA) studies?”

More direction on development of baseline. More specific manufacturing EPDs. More flexibility in concrete and SCMs inputs, in input on distance of extraction, manufacturing, and supplier distances to project site.”
Architecture, works all over the US

Tally is a bit of a black box and it is unclear what data they are using and if regional (or other) modifications should be made. Also, how sub-elements are accounted for (ie, fasteners or other items that are small but cumulatively could offset the balance). It is complicated and there should be more guidance for design professionals because we are not LCA experts.
Architecture, works in West and Northwest US

“Larger effects of timber material extraction from forests on ecosystems over the long term, compared to potential long-term effects of embodied carbon and GHG potential of concrete, masonry and steel.”
Architecture, works in the US

“From your perspective, what topics regarding structural materials’ manufacture, and construction methods would be most beneficial for designers and policy makers to understand?”

“a design guide that lays out issues and common patterns so that the very early design moves are not made while uninformed”
Architecture, works in the Southeast and Midwest US

“the environmental impact of steel and concrete relative to wood”
Architecture, works in the Northwest US

“Having some widely available info comparing different structural methods and their environmental impact vs cost impact regionally would be extremely beneficial to share with clients”
Architecture, works in the Northwest US

“carbon footprint of manufacturing”
Architecture, works in the Northwest US

“If we are to use wood, we need a clear consensus that it is an environmental improvement over other materials. Ways to reduce end of life impacts are also critical as are forestry practices and how climate change is impacting forestry.”
Architecture, works in the West and Northwest US

“embodied carbon, habitat impacts, overall sustainability of resource, impacts on local economy and jobs”
Architecture, works in the West and Northwest US

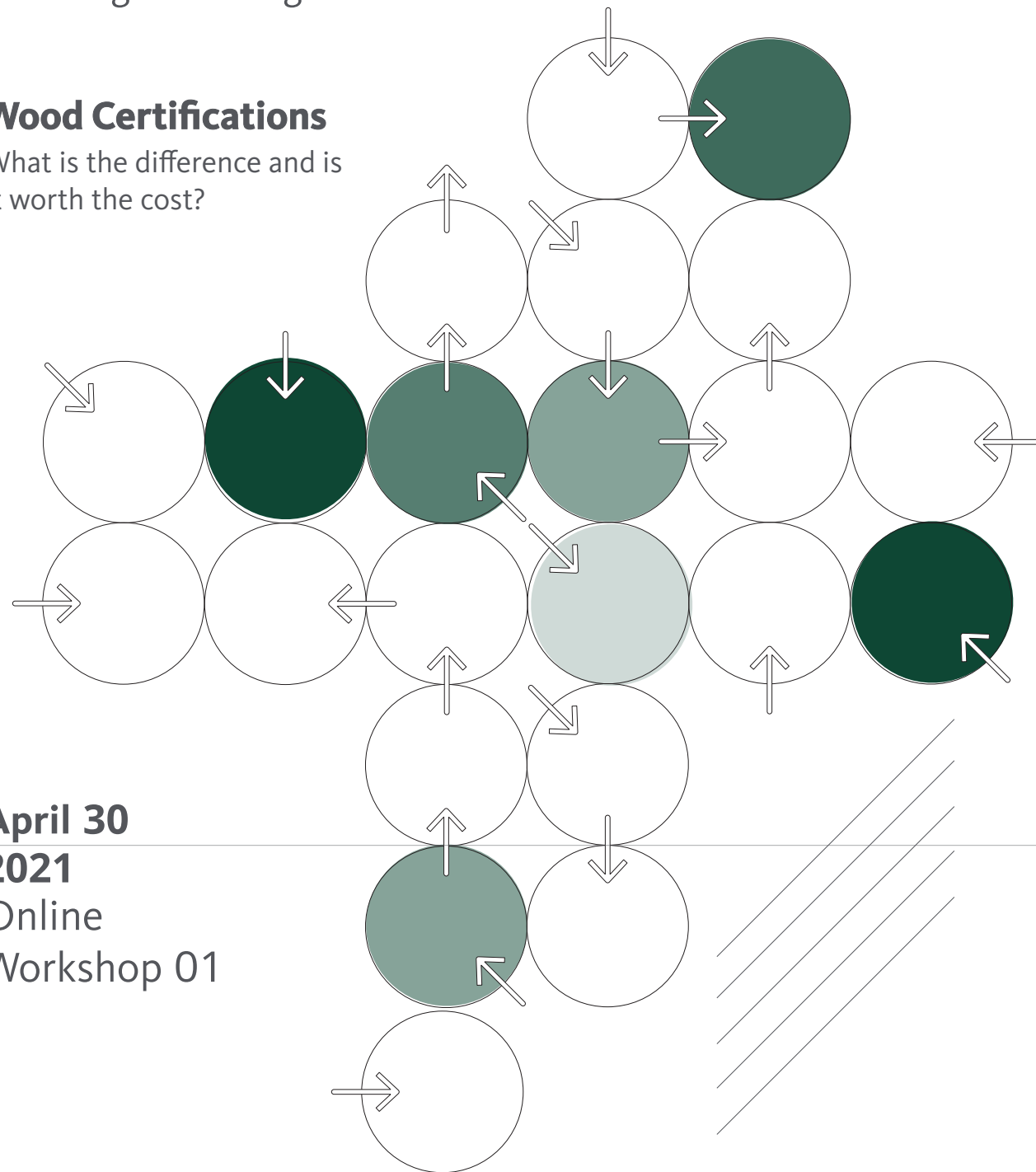
“...ways to reduce end of life impacts are also critical”
Architecture, works in the West and Northwest US

Carbon Narratives

for Design Planning

Wood Certifications

What is the difference and is it worth the cost?



April 30
2021
Online
Workshop 01



TALLWOOD
DESIGN INSTITUTE



CORRIM



This work was funded through USDA Agricultural Research Service (ARS 58-0204-66-002) grant and in association with TallWood Design Institute

Panelists

Laura Chessor // Certification Officer

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Campbell River, BC. SFI Program Participant in BC, CSA Certification, FSC Forest Management Certification in PNW

Ara Erickson // Director Corporate Sustainability

Weyerhaeuser, Seattle, Washington
SFI Program Participant in PNW

John Henrikson // Owner

Wild Thyme Tree Farm, Oakville, Washington
ATFS Certification, FSC Forest Management Certification in PNW

Mike Warjone // President

Port Blakely Tree Farms, Olympia, Washington
SFI Program Participant in PNW
FSC Forest Management Certification in New Zealand

Question and Response

The first of the workshop series will center conversations around North American forest certification programs. Panelists of foresters representing small, medium, and large-scaled operations, will candidly speak about forest management practices in the Pacific Northwestern United States and Canada. Their “boots on the ground” perspective will provide invaluable insight on how the AEC’s desire for wood building products impact local ecologies, economics, and overall forest sustainability. The complexities of what it means to select wood from certified forests vs non-certified forests, costs with running certified forests, and the misconceptions and understandings of what our design decisions mean when we select structural wood and wood products will be covered from forestry perspectives. Please come join us with your questions for an informative Q&A period following the panelist presentations.

1. Can we discuss the future in terms of the economic value of certified wood versus the current fossil fuel economy. Does the “green New Deal” see the current & future value of certified wood?

Elaine Oneil – I am not sure anybody has a good answer to that.

2. Two part question for the panelist. There was a slide that had a limit of 60 for FSC forest. Does this refer to 60% of the land area? Second question, how can designers best specify wood that is also linked to some form of carbon sequestration program or certification?

Elaine Oneil – The 60% refers to clear cut size. There seems to be a perception out there that we can do perpetual thinning and that that would be biologically advantageous. I think Mike alluded to it. In the Pacific Northwest, our primary focus is Douglas Fir. Douglas Fir doesn’t grow in the shade. So yes, you can thin, but at some point, you are going to have to clear cut to re-establish Douglas Fir. And in fact, that is true for most of the dominant species that we grow in North America, if you think about it. Southern pine, pine forests, pine is typically shade intolerant. It doesn’t grow in the shade. You can do all sorts of things, in terms of, these partial harvests and growing trees

bigger, but eventually, you have to harvest that, open up the canopy so that you can reestablish a new crop. The same factor applies in British Columbia. In fact, most of our species that are the dominant species, and the species people like to build with, you can some white woods in the shade. Not very effectively. But mostly, architects like to complain about the quality of whitewood.

Mike Warjone – (in response to the second question) That’s tough. Frankly, the rest of the world has sort of figured this out already. The US is way behind on this sort of recognition of forest products and the built environment. The work you all are doing is really fantastic and we are making progress, but I look at New Zealand. 20 years ago they made a decision, and Scandinavian countries they made a decision. Western Europe made a decision to really move away from fossil fuel intensive building materials. They baked right into their building codes and their laws all those things that we started exploring with the Tallwood Design Institute. We’re just behind. In every case, if you are building it out of wood, it’s the best option. No doubt about it. If you want to support companies that have specific carbon forest projects, there are certification programs out there like the American Carbon Registry. We have a 10,000-acre forest selling carbon credits out of it. It is a voluntary project in Washington. It is managed on a longer rotation which allows for this. You are never going to find that stamped on a glulam.

So, it requires some real business to consumer marketing on the part of the people who have those forests, and it requires a genuine interest on the part of the architects that are doing the work. We are selling the carbon credits, but frankly, it is not covering the cost of producing them right now. And so, in New Zealand, every forest is automatically registered because it is a government program that says, “If you are growing a tree, there is carbon there and we want to talk to you about it”. Here, it is really tough. It would require a very progressive client who really wanted to not just buy the sales pitch, but dig deep and find out from a strictly carbon perspective, what am I buying? And then follow that chain of custody clear back through to the stump. There just isn’t a good mechanism in place for that right now. I think we are getting there, and I think that the industry is doing a lot of good work with “flux”. The number you should all be concerned about is flux. Where is the changing forest landscape? Where is the forest dying and where is it growing? Support the areas where they are doing forest restoration work. Support the areas where they are harvesting dead trees that are now becoming emissions. Frankly, on the West coast, a lot of that is on Federal land. Support the communities that are trying to get back into those forests and doing that restorative work. If you are really interested, look up the American Carbon Registry (ACR) and look at the companies that have voluntarily committed their wood and selling their wood. In our case, a lot of that is going to Weyerhaeuser. You have to have some sort of leap of faith there in the US because we haven’t gotten our act together on that direct line back to the forest.

3. Several speakers highlighted various impediments to FSC such as higher costs to timber operators. I am curious about the nature of these costs (human time, equipment, education, etc) and whether there are discussions around how these costs might be subsidized to reduce impediments to certification.

Mike Warjone – The cost for us, as far as achieving certification on FSC or SFI is about the same to be honest. But as small timber companies go, we’re pretty big. As you have fewer and fewer acres to certify, that economy of scale goes away. I think the cost of certification, that is paying a third-party auditor to come and do that work, it is very often the same auditor for FSC and SFI. The auditors can certify in both. So that cost is about the same. It is really about

what is the impact on your ability to operate under the two different regimes. SFI is scaled well for companies our size and up to Weyerhaeuser size. That is really what makes sense. I think FSC is good for small landowners because they have more flexibility as far as the audit, where they actually come out and check and see what you are doing on the ground, is more manageable. Where SFI just doesn’t have anything that can scale that small.

John Henrikson – (in response to Mike’s comment about small landowners find it easier to be FSC certified) The price is nominal. For me, it is a few hundred dollars a year depending on whether I harvest or not. So, that is definitely doable. I think its more appropriate for municipalities and land trusts that have other objectives besides timber harvest. It is a better fit for them. I think most small landowners are not going to want to pay the price and the associated record keeping and constant monitoring. That is for really active landowners, people who are really ‘gung ho’ about it. There’s going to be a kind of natural barrier there. That’s unavoidable compared to like, Tree Farm System, which is much more accessible that way.

Ara Erickson – When we have looked at the cost of FSC compared to SFI certification, the cost of the programs are the same. At least to a company at scale. Our true difference of cost comes down to in certain, very restrictive practices like what is prescribed in the Pacific Northwest, the ‘leave tree’ or retention amount in the Pacific Northwest. It would be asking a company of our scale to leave 40% of the volume on the land, which means that it is not going into the supply chain so we can not build a building from the wood that is still growing or still on the landscape. To break it down to basic numbers, that is a huge amount. It is like asking the potato farmer not to sell 40% of their potatoes. So as a company, that just doesn’t work for us. When we think globally, where do we then get that material? So, to Mike’s point, it is about the unit of product we buy. What were the impacts of that 2x4 on the landscape? That’s really what we need to be thinking about for companies at scale, not necessarily every landowner. When we say ‘cost’, we mean that it would really put us out of business in the Pacific Northwest which I think, personally, is a challenge if we decide to not harvest trees in a highly productive area. I wanted to touch on cost because I think there is a misconception out there that FSC is just “more expensive and we don’t want to do it”. I’d like to make certain that this audience knows that is not the case.

4. Could the panelists please discuss some of the key differences between the forest practices laws in WA and OR, and how the certification systems address those differences. how different is SFI/FSC wood from WA vs OR?

Ara Erickson – As far as differences, I think of certification as raising the bar for everybody. What’s really great about SFI certification, it makes everyone meet a certain threshold. FSC also has to meet a certain threshold within that region. Since there is not just one FSC standard, I can not speak to what bar it meets. It is different across the world. But as far as SFI, it levels it. So, there are rules that we need to follow within each state where we operate, whether its in Canada or the US. Those are going to differ based on those local forest practice rules, federal, state or things like the Endangered Species Act which we all have to follow. But certification means that everybody has to come into that bar. The clear cut example one. It does require that clear cuts can’t be larger than 120 acres anywhere that the SFI standard operates. Now in the Southeast US, there are not as strong forest practice rules as there are in Oregon and Washington. Oregon’s is different than Washington’s which is different than California’s. If you are SFI certified, you have to meet that same threshold no matter where you are. So it really does raise all management across the system so that people are doing one, the same and two, better. We also have to meet

the rules and the laws of the state where we operate. So that's going to be different, for now at least, for Washington compared to Arkansas. If we have the SFI stamp, then we have to meet a whole other host of other requirements. I know we are focused on some of these small nuances right now like, leave tree retention and clear-cut size, but FSC, SFI, and ATFS address a whole host of other things that are not required by anyone, anywhere. I will use a couple examples. Working with SFI's fiber sourcing program and forest management standard program requires us to invest in forestry research, outreach, and education. That's not required in any state law. We are going to continue to have to do that. We invest millions, billions of dollars in that type of outreach, education, and research. That's unusual and that's something that certification requires that's voluntary and part of the program. It is going to improve forestry for everybody. Another example would be working with indigenous communities, particularly in areas of First Nations in Canada, and also with our neighboring tribal lands in Oregon and Washington, for protecting cultural sites and heritage sites. That is not required under state law right now. Those are all parts that are included in the standard. I think of certification as raising the tides for everybody.

Globally, we are hovering at about 10-11% of the forests certified. There is not good forest management happening all over the world that has some sort of stamp of approval on it. We are talking a really small percentage. A lot of industrial land and commercial land in the US, Canada and New Zealand is certified, but not everywhere. Certification is another whole host of requirements that we have to meet and I encourage people to really explore both the SFI, FSC, and ATFS. Look at all the details that we as landowners and managers need to be doing in order to meet that certification. It is not just about clear cut and chemicals, it is far more intensive. The teams in Weyerhaeuser who manage our certification programs and the foresters who are on the ground getting audited, they know it is far beyond what we would normally be doing without our certification program in place, to the tune of millions of millions of dollars to thousands of hours of staff time and how do we change our operations and do our work differently.

5. Mike - you mentioned that you can't make an environmental judgment between FSC in New Zealand and Washington State --- which makes total sense. But what about making an environmental judgment between SFI in Washington and FSC in Washington?

Mike Warjone – FSC has done a wonderful job with marketing FSC. And I was involved with some of the early work of writing the FSC standard for the Pacific Northwest and working with the team at the time. But really, there is a lot of stuff there that's frankly more about optics than biology. And so, FSC, if you want to get in on that market, you are going to have to do some things on the landscape, smaller clear-cut size is one of them. There isn't really a biological reason for that, or a conservation reason for that, but it does talk about the social license to operate, clear-cuts are ugly. If you want your forest to be visually appealing, it is going to look better under FSC in some cases. As far as the science goes, there is no, in my opinion, biological advantage to FSC over SFI. Or the other way around.

I like to think about the specific effect of the wood, that is to say, a 2x4, 2x6, or a glulam that is coming out of a facility, what is the impact on the environment of that thing clear back through the whole chain of custody? And if that is how you are doing the math, the number of acres that it took to produce that volume of wood, you are not going to find a difference between the two from an environmental standpoint here in the Pacific Northwest.

6. I think we need to find a way to show data with comparable units (tons of carbon) that allow us to understand timber source's relative carbon benefit. And it is best for the industry to be able to show there is a net carbon benefit to harvest compared to letting the forest grow in a managed way. How can we do that in a way that allows architects to specify a particular product with confidence of a net carbon benefit?

Elaine Oneil – Are we maintaining our forest carbon stocks at the same level or increasing? How do you measure that? How do you measure, not just what is going on in the wood, but also what is going on in the soils and the rest of the ecosystem? I think most generally in the US, for example, we have something the USFS measures and monitors on a yearly basis and has been doing for probably for 40 years, maybe longer, the Forest Inventory and Analysis Program. And what they do is they remeasure every 10 years in the West and every 5 years in the East on these permanent plots and they look out across the landscape and are going “are we growing more wood? Or are we growing less?”

If we are growing more, than we have more carbon, therefore increasing in carbon stores. If you are growing less, you have less carbon. In fact, in the US at large, we are storing more carbon than we are cutting. If you break that down regionally, the one place where we are starting to lose more carbon than we are growing is in the interior West. Most of that is Federal land and most of that is due to fires, insects, and disease. The Southeast, through their environmental management and pretty aggressive forestry operations, has actually doubled their forest inventory in the last 20-30 years. They are storing more carbon than they ever did. Basically, replanting a bunch of fields that used to grow cotton and are now growing loblolly pine that is going into the supply chain. The Pacific Northwest is kind of a mixed bag. We are losing some of our forests to wildfires, insects, and disease. That seems to be getting worse over the years. We are also losing a bunch of them due to development. On the forests that are continuing to be managed, we haven't shifted our storage over the past 50 years. The case is a bit different because of the mountain pine beetle outbreak.

Laura Chessor – In the interior of the province, we have had a fairly long-standing epidemic level of mountain pine beetle which has killed off vast areas of pine forest. And then the dead standing wood there obviously creates a risk for fire and there is also a natural history of large-scale fires in the interior. The province was looking to increase the salvage harvesting of those areas to try to reduce the fire load of that standing deadwood and also utilize that wood. There are very large programs to replant those forests and bring back forested ecosystems. In terms of carbon, trying to salvage the forested areas and utilize the wood and remove it from the landscape before it becomes an even higher risk, especially around communities that are potentially surrounded by dead forests. Replanting with native species and encouraging that regeneration of the forests and bringing back both the timber value and the wildlife biodiversity value and carbon sequestration values.

7. Mike - my understanding is that Port Blakely recently participated in one of the largest, if not the largest, state Habitat Conservation Plans for one of its forests in Pacific County, WA---which required management above and beyond the regulatory floor. Which is great --- can you talk a little bit on what that HCP entails and what drove that decision?

Mike Warjone – It is a Federal HCP. We are entering our 25th year. I think this

question may be about our state stewardship agreement in Oregon which just recently was signed. I can talk about both of them; both of them have the same objective which is, we take a generational approach to forest investment. What that means is we need some regulatory certainty to make these decisions on the ground about leaving barriers and buffers. If you're going to plant a tree that you are not going to log in 50 years, you need some certainty that the field you planted in is not going to be rechecked underneath you. Whenever we have the opportunity to do some work and recreate habitat and provide a landscape level of what the view is in 50 years from our management, we will engage with the federal agencies, both the US Fish and Wildlife and NOAA Fisheries, and come to an agreement about that. We put together a plan under the Endangered Species Act that says "we will provide for these endangered species and when they show up, we will not be penalized for having created habitat for them to come and live in our forests". We see it as a good long term risk management strategy, from a business perspective. And it enables us to do things like carbon projects and all this other stuff.

Ours is not the biggest, ours is not the first. There are plenty of other companies, like Weyerhaeuser, that have a Spotted Owl HCP in Oregon as well. It is a good way for a company to be proactive about what is an obvious c-change in forest practice rules. Saying, "what do we need to do on the ground to provide for the resource and the animals that need it to be there including all of the stakeholders: the users of the water down the stream, and so on". And lock that in. There aren't that many businesses that think in terms of centuries. Forestry is neat that way. When we are talking about trees, this is a long-term deal, and you have to engage in these things in a way that makes sense. If you know you are going to be here a long time, you need to watch the luxury of doing that.

8. I'm interested in zooming out in this discussion: it seems the premise for third party certifications is based on an assumption that government regulation (business as usual) does not provide enough assurance that the timber industry to sustainably managing forest lands. As timber industry representatives, what is keeping the industry from lobbying for stricter governmental regulation of the timber industry so that certification systems are no longer needed?

Elaine Oneil – As somebody who has been sitting on a standards committee for incorporating biological materials into the circular economy, one of the things that we learned as we were looking at how to build that into a global standard, was the challenge we face in different countries and different regulatory floors. How do you know that the wood that is coming from Guyana, or somewhere in Asia, actually has a regulation baked into it. One of the easy ways to do that is to make sure that wood is certified. There is a difference when we talked about wood procurement and understanding and knowing it was sustainable. There are certain regions in the world that have a strong regulatory base and for those ones, the certification is like the cherry on top of the pie. If you're sourcing timber in other parts of the world, it may be the pie. There's an answer within this question about how do we make sure that, if this is beyond business as usual, in industry in all places isn't lobbying for laxer regulations.

Ara Erickson - I want to make certain that it is clear that certification is not there because forestry, particularly in North America, is not strict enough. It really goes back to what customers want and they want to see a stamp of approval that a third-party group has verified something. When I go buy a USDA organic stamp, I want to see that somebody else calls it organic, not that the company told me its organic. That truly is what certification is – a

stamp of approval for meeting a certain set of objectives. It is also improving forest management on all types of lands and improving visibility into the supply chain. We do need better forest practice rules across the entire world, particularly in countries with incredibly lax environmental regulations. Certification does allow for that comparability from a country that may not have rules to a country that does. That depends on what certification you are buying.

We work very closely across our jurisdictions. What are the types of practices that we do need to be improving? We are in the middle of a long-term MOU with Oregon to really redefine forest practice rules with the environmental community. That is what we like to do. We like to talk to people and see what improvements to practices are. What are we looking for? What is the right way to get there? Are we going to use science to inform that? How are we going to end up in a place where we ultimately still provide fiber to the world, benefits to the world, as well as keep the forestry industry and landowners of all different sizes still operating.

Mike Warjone – There is this tension between the certification schemes in Oregon specifically right now because Oregon is in the middle of renegotiation of forest practice rules. We definitely have to talk about the footprint. There is this idea that we need 5 billion board feet of timber every year out of the Pacific Northwest just to keep the lights on in the built environment. That's got to come from somewhere. You can have a light touch on a lot of acres or you can intensively manage a few acres. If you are talking about FSC v SFI that is kind of the deal. It gets back to that specific impact of every board that comes out of the mill, some tree had to be cut to do that. If you are trying to get a certain amount of volume out of a large area and just cutting a few trees, you are building a lot of roads and your impact is there whether you are making it a clear cut or not. In the Pacific Northwest, we have to live in a place where intensively managing a smaller area can be done responsibly. It does not work in rainforest and tropical rainforest. And it is very difficult, as Laura can point out, to do in the Boreal forest of northern BC where you are on a 100 year rotation to get a small tree. We happen to live in a spot where this works really well. I am a big fan of preserving the old growth, preserving the parks, and letting the people in the business of growing trees do their work to supply the fiber that we need. FSC is leaning towards conservation versus management. That's why the SFI model fits for this area so well.

There is nothing biologically different about it. You are still cutting a tree down and turning it into boards. You are still replanting it every time and for every tree that gets cut down and the cycle repeats itself. The watersheds are being protected. It really comes down to marketing. We could try and push, but we are the industry, so it is up to the consumer to make that decision.

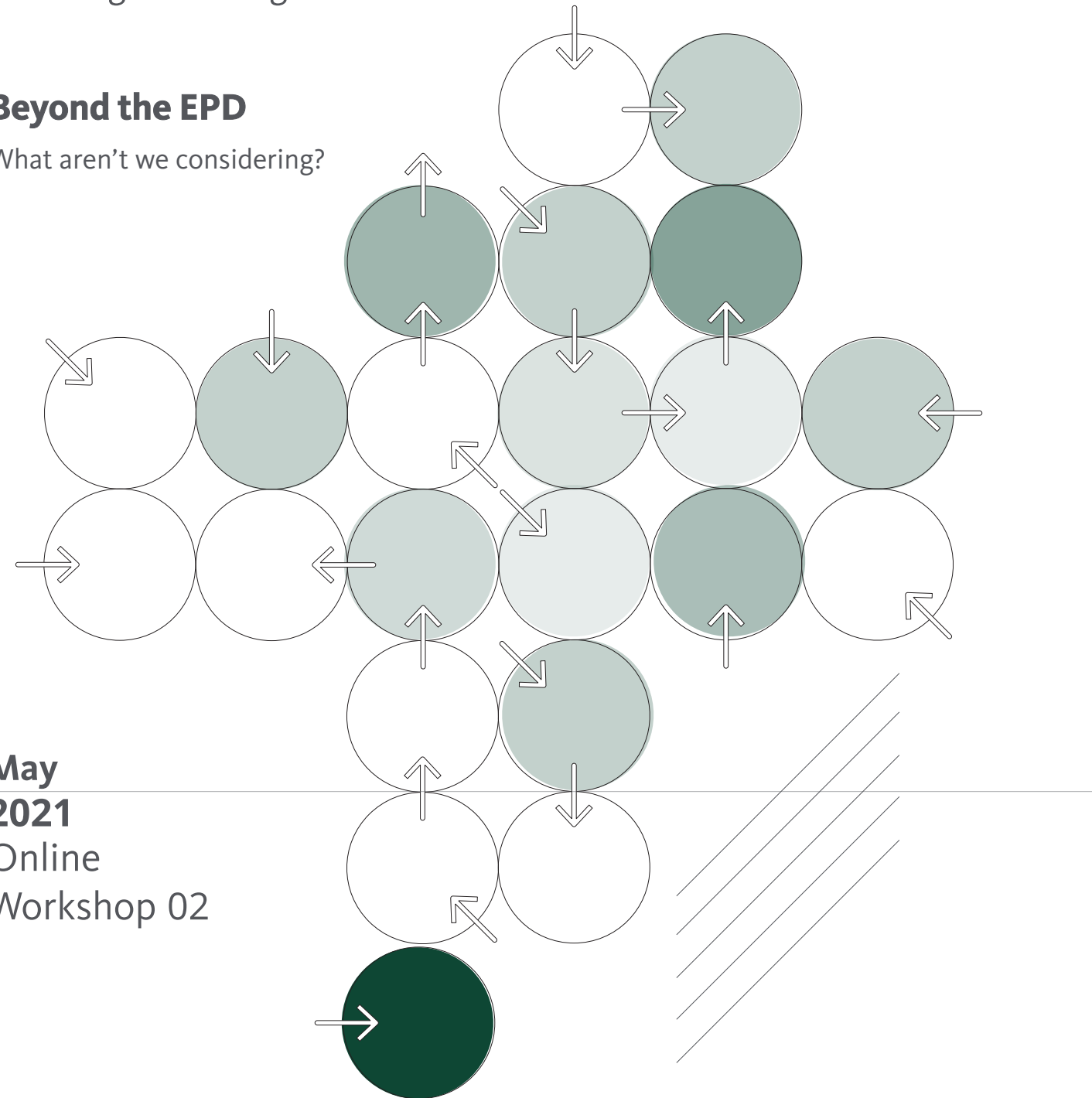
Laura Chessor – Coming out of BC, the regulation is really rigorous. You can be confident it was managed to a high standard. But we can't expect customers and people that are sourcing products to understand and delve into that level of detail of regulatory requirements of an individual province. So that is where certification provides that comparability. The label that customers can see, recognize, and know what it is about. The regulation approaches it from "what are the values that the public wants on crown land, so how do we protect biodiversity, water quality, and make sure those values are present that the public wants". And the certification gets into a lot more detail at the operational level on how to provide those things. The government sets the bar "this is what we want". The certification makes sure we have verification that there are systems in place that provide those values and makes sure our operations will meet all those values. As well as some additional values that are not covered by the regulation.

Carbon Narratives

for Design Planning

Beyond the EPD

What aren't we considering?



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Elaine Oneil // CORRIM
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Mark Wishnie // BTG Pactual Timberland Investment Group
Chief Sustainability Officer
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Question and Response

The second of the workshop series will explore large scale implications of forestry practices, such as extensive or intensive harvesting, on surrounding communities, interrelated ecological networks, and global climate change. Members of the AEC industry seek clarification on how their roles and decisions in these various practices will impact the environment. The panelists represent a variety of backgrounds all unified around the questions of economics, equity, and ecology regarding the use of timber and wood building products. The facilitated conversations hope to distinguish between idealized scenarios and actual realities when it comes to advancement in forestry practices and the regulations of forested lands.

1. For Mark there is a question about your 2019 mass timber conference. Two years later from that talk you gave there, the urgency continues to grow while little continues to change. In regard to the social license issue that you brought up, what lever should the architecture, engineering, and construction community really be pulling to provide more impact? And what research can we all do to provide and contribute to moving the dial and filling the social license gap more effectively?

Mark Wishnie: That's a great question. There is a colleague of mine in the environment community who likes to say that architects are to the forest industry as celebrity chefs are to the organic farming and farm to table movement. That is architects, developers, and folks that are looking to source mass timber materials, or other biomaterials, are terrific spokes people for the potential of biomaterials to contribute to the climate solution. There is a long history of debate and conflict around forest management, particularly in the Northwest among the environment community and forest industry. What I think the architecture community can offer is simply a new voice in the conversation and a new entry point. We already see that in federal legislation and in state legislation there are a number of proposed bills that would provide for example, a tax credit for low embodied carbon buildings or a tax credit for wood in construction. And that I think is really creating an opportunity to change the discussion around the role that forest products can play in serving as a climate solution. Of course, architects can't do it alone. I think industry needs to really step up and lead the way on sustainability. A lot of industry actors like to argue that the industry is great. That it is doing a great job at managing forests and that their great performance needs to be recognized. In my view there is some truth to that, but I think it's also true

that the industry can do more and needs to do more to demonstrate that it can be entrusted with providing a sustainable, renewable biomaterial. The mass timber discussion is a pretty good carrot in terms of enticing industry to take new actions and be part of that discussion. Most folks in the timber industry would much rather be in a conversation with architecture, designing beautiful new buildings that showcase wood products and designing new headquarters buildings for leading brands. And to be a part of this really compelling story about turning cities into carbon vaults and into carbon solutions. That's a much better conversation than trying to explain one more time why sustainable forest management is sustainable. I think that the firm I am with now and others like it are starting to take steps and are willing to take steps to do more to be able to be part of that conversation. I think this kind of seminar is terrifically important. Having architects ask these questions and insist on ensuring that materials are sustainably sourced and are good for the planet and for people and for nature. I think that is all in fact really helpful. The industry and the environment community need to sort of step up and join in that conversation.

2. Back to Mark, thinking about that sawtooth graph you showed that managing forests have a two to three times carbon benefit than the forests alone, the question is: the two to three times calculation based on an unmanaged forest, your example was using eucalyptus on a 25-year rotation, but wondering how this works on Douglas fir which doesn't reach biological productivity until 150 years plus. It seems like the benefit management maybe less than two to three times in this case or take longer to come to fruition.

Mark Wishnie: That was an example and not every forest delivers that result. The point I was trying to make is that when we do this well, when we optimize across these systems, we can have really significant benefits. But if we have some management which is degrading forests, such as high grading which is sort of an unsustainable practice. It is unfortunately common say in the Northeast. If the products we are harvesting are going to short lived applications or going into paper, which is a useful product but has shown high emissions per unit on production, you can have negative outcomes. The system matters but we can't let that complexity stop us from taking action. I think that's what all the speakers have been talking about. There is a lot of complexity that underlies this, but when we get it right, we can have very positive outcomes. To the specific question about this experiment with the Northwest, I think Indro addressed that and gave an example on one of his last slides.

Elaine Oneil: I had some thoughts on this having looked at forest inventory at large across the Pacific Northwest for 30 some years. You need to unpack this in a bunch of different ways. If you're intensively managing, if you're planting at pretty high densities, making sure that all the trees survive, and taking them out as a crop, then you have the time value of money that you have to think about. This idea that if you're starting with a forest that is already fully stocked then yes growing it longer, which I did demonstrate, will add more carbon on that particular acre. But if you actually look at the inventory, say from 1953 onwards, are we degrading that standing inventory? I did this in a project I published two or three years ago because I was interested in what happens in the Pacific Northwest over time. Are we degrading the standing forest inventory? In fact we are not. So, the average standing inventory out there in the forest in the 50s, is about the same as it is now even though we have all these folks managing much more intensively. That actually makes sense because what they are finding under intensive management is that over time those standing inventories values will converge. In the Southeast for

example, they're getting the same height growth and nearly the same volume at 20 years as they would have at 50 years. But if they left that stand to grow until it was 50, it would converge with leaving it an unmanaged stand. I think there's this thought process out there that our inventory is a lot less than what it was 50 years ago and that's actually not true. That's not true in Washington state, Oregon, or British Columbia where they did have old growth that they inventoried and compared it to second growth. I think we always think of the Tiger Woods of the forest as something that is obtainable everywhere. We're not all Tiger Woods and neither is the forest. We have to think about how did that stand get there? Is it fully stocked or was it fully stocked? One of the things Indro showed, and maybe he has some explanations in that data, is that the small forest landowners, the non-industrial, are way lower. I think that is because they are not managing but I don't know how you can explain that particular thing.

Indroneil Ganguly: Yes, thank you for the segway. Actually, the data I showed was for Douglas fir. We clearly see that if we expand rotation and not manage properly, the gain we have seen in the US forest service is to stop harvesting, essentially expanding rotation. We are not managing it. That is an important point. We are only 65% over what the carpet forest is. But then when we look at the wood products in the system, that goes away immediately on top of substitution effect. It is actually bad policy to expand rotation in Douglas fir. To David's point, in his presentation yes we can do better. But we can always say to Michael Phelps if he were a little more disciplined, he would have gotten more medals and everyone else is fine. We don't have to be disciplined. There is always this tendency to be better than the good student in the class. To your point Elaine to the small private land, it is because they are not managing. In fact, the models we use, we used the same model in the paper we published, if we apply them to small forest landowners they do really good production. That is the same mistake people do in putting those FDS models in federal forest and they see amazing production. When the actual data came out of FIA, we said no it's not that amazing production because we are doing the mistake of using a managed model for an unmanaged stand. That is where the 150 years comes from. One tree kills all of the trees around it and suppresses all of the trees around it. I will stop there but it is a complex issue. The more we simplify it, the more we complicate it. Wood is good is a bad thing to say. The more we simplify things, the more we inject the confusion. This detailed analysis is what is needed at this point.

David Diaz: Yeah, I will pile onto that and say I don't think we are really talking about bad sources of wood in the United States in particular. I want to be clear that as Indro said, I am not trying to "beat the good student" here. I do think the real opportunity here is incremental improvements and marginal improvements. When I was describing financially optimal versus biologically optimal rotations, we don't need to let the rotations go to 150 years for Douglas fir for example. Going from 45 years to 55 years we would be producing more timber per acre per year and storing more carbon per acre per year. We are getting closer to this even though the latest industrial plantation yield curves are suggesting that if we were harvesting at a rotation of 70 to 75 years that is when we would be maximizing timber output from Douglas fir plantations. If we actually acknowledged and integrated the value of carbon, or other services, into the forest management decision framework, we would see these incremental improvements could be massive. This is the same type of decision that if Walmart can reduce water use in its processes, you add that up its happening billions of times throughout the supply chain. That's where even doing something like increasing rotation intervals on each Douglas fir acre by one year, its not going to change habitat or water quality, but that one extra year of growth is going to have a substantial aggregate impact.

That is the direction that if we valued carbon or other services we would be nudging things. It's not as charismatic as a tropical rainforest conservation project, for example. But in terms of emission impacts, there's a lot of room for improvement there in terms of carbon sequestration and wood production as well. Once we get to those longer rotations you get a higher utilization of the logs that are produced that can go into long lived products compared to doing the shorter rotations. We don't need to have longer rotations be cast as if it was way beyond the biological optimal output.

Indroneil Ganguly: I completely agree with that statement David. That I think is what the right approach is. We know the carbon credits; we can do better. We can help the industry do better, but when we extend it suddenly that one, two, three years gets extended to 50 years. That is what we have the tendency to do. We have done that in 1990, we know that, and we are suffering today.

David Diaz: At least in terms of where most of our wood comes from, I don't think we are going to regulate our private timberland owners into something like that. I think that would be politically way off the charts. I think what is more likely to happen here are these kind of incentive programs, either on the demand side for using more wood, or some type of carbon payment system. We are going to see marginal adoption. It's not going to be mandatory that everyone is forced to do anything. It's just going to be those timberland owners and timber product suppliers that say there is value in actually trying to go after this to opt in. I'm not worried about there being a sort of regulatory wave that is coming associated with this, but maybe I'm less risk adverse than others.

Elaine Oneil: I think it is important to understand how wood is a global commodity. So, David's right you would get a higher yield with larger diameter material. That 50% might go up to 60%, or something like that. I've been asking folks here what's happening in the Pacific Northwest. The answer is, we can get more money sending that big log overseas, so we are not going to gut more than 50%. It just goes somewhere else and gets used by someone else other than the US market or the North American market. Normally it would go to Japan or China. The challenge is to think about how to influence a global commodity market. Are you influencing it with, I'm going to call it Home Depot quality wood, or are you influencing it by demanding the Saks 5th Avenue wood? For an iconic building you are going to want Saks 5th Avenue wood, you're not going to want Home Depot wood. But for many buildings, the idea of management intensity probably needs to be unpacked a little bit. We are getting down into the forestry weeds Mark. They are probably rolling their eyes.

3. This is a great discussion. I think you may be answered one of the questions there that was on the graph you showed Elaine, but that was also something people had questions about. I wanted to make sure that we saw the graph and gave Mark or David an opportunity to look and respond to the question, if there is any additional volume between a 30-year harvest rotation verse a 50 plus year rotation in the Pacific Northwest over a 100-year period of time?

Elaine Oneil: The answer is yes. There is no difference. I was as surprised as the person that asked the question was when I tracked this. I looked at the inventories at those given age classes by the number of acres, so they had different age class distributions. I took the midpoint of each one of these and charted it. I was actually pretty amazed that we were having that kind of yield at that early age. Now like David says, they are not as big at 32 as they are at 52, so at what age do they harvest? Well, that depends on the market.

If there suddenly is a huge demand in timber, like there is right now, people are probably logging a whole bunch of stuff that they otherwise couldn't reach. Maybe its lower quality stuff, a stand is just not performing. This would represent some pretty aggressive management to make sure those stands are fully stocked and it's mostly trees growing there. This is for the timber producing acres. This is not for the acres that are reserved. David used that cool little chart about all the riparian reserves and there are steep and unstable slopes and a whole bunch of stuff. Washington state has over half its forest lands is off-limits to harvest. You just don't harvest that. I think of that half that's off limits there's maybe anywhere from 10 to 20% on private forest land that's off limits to harvest because we are protecting water, we are protecting salmon, we are protecting endangered species, unstable slopes, and all those sorts of things. It's a different percent in Oregon, I don't have that off the top of my head, but this is kind of stunning to me. It assumes that you harvest and then you reforest that these guys are in it for the long term. I think we have a pretty good reputation in the Pacific Northwest of that being the case. You know this is called the evergreen state for a reason. We have companies moving here and out of other areas that are less viable from a regulatory perspective or a financial perspective. I think this bodes well. It's real inventory.

Any other quick follow up on that?

David Diaz: Yeah, I can take that. I don't know precisely where these data came from, but one of the things that I have really been encouraging in general is that we should not be thinking exclusively about the yield and solid wood. We also need to think about how much carbon is standing in live and dead trees, above and below ground, and things like that. So that would add some nuance to this that would look a little different than this current chart, which is showing saw log volume and pulp log volume coming out of some forest in the Pacific Northwest. When we look at the yield curves that are being generated by research plots installed on industry land across Western Oregon and Washington, the latest research coming out of the Stand Management Cooperative is still suggesting that the 60-to-70-year rotations would be when we have wet forest. This would be the culmination of mean annual increment. I can't diagnose whether this graph conflicts with that, but the other thing to remember is that when we are harvesting the trees and converting them into logs, there is a lot that was standing out there, both the branches and tops and all of that are not making it onto the truck and into a product. That is going to grow over time as well too. The longer that is standing over time keeps more carbon out of the atmosphere. I think there is this kind of challenge of monitoring over time where we need to see how much came out of the atmosphere and into the forest, and how much is continuing to flow into the product pool that make some of these determinations a little more challenging.

Indroneil Ganguly: Just a quick comment, I agree with David on that we should look at the dead trees and the standing dead and all the roots and everything. One of the things we know, and David also in his talk mentioned how you need to consider methanisation, that becomes a problem. We need to factor in dead trees yes, but then in the wet forest here in the Pacific Northwest, methane emissions can make a huge difference. Keep perspective, we are not counting carbons here, we are trying to look at forest as a climate solution and global warming solution. Counting carbons would not factor in methane emission as anything different to CO2 emissions. I think perspective is important, carbon is not global warming in this particular discussion.

Elaine Oneil: Go ahead Mark. And then I want to help people understand the

difference between David's perspective and my perspective because I think that could generate a whole lot of confusion. We're actually both right.

Mark Wishnie: Okay I have two comments. The first, I don't know the data behind this graph either they didn't tell me the description behind it. When I look at this graph, the period of time, the age of trees that Elaine is focused on here is right around both thinning and commercial harvest. In these forests we typically go into harvest 2 to 3 times. So, there is a final harvest where we do a clear cut, but then we go in once or twice before that and we cut some trees and remove those. Those are usually small trees and we leave bigger trees to keep growing. When we do a thinning, we reduce volume, even though the stand is a 30-year-old stand or 40-year-old stand. The trees regrow from that thinning and the trees that we leave behind get bigger until they grow back to what the volume was before we did the thinning. If we let them keep growing, then they grow beyond that. I assumed that if we were to add harvest volume to this graph then we would actually see increases over time. I assume there is thinning in here and with the noise sort of in the data that's happening at different ages across the landscape, we are seeing this flat curve. I don't know if that's the case but that's my assumption.

Elaine Oneil: That's why it's important that I clarify this. Actually, that is not right on. This graph represents the standing inventory divided by the number of acres it is standing on. This entire thing represents 300,000 acres in the Pacific Northwest, so it is not inconsequential. It's basically west side Douglas fir. You take the standing inventory on that number of acres, and they're identifying what the pulp volume is and the sawn timber volume on that acreage in that age class distribution. So, you just chart it. Obviously over time, just like David says, you get more volume per acre for each one of these stands because it does keep growing. That's the point that David makes. For this acre if you just let it keep growing that's great. But if you're planning on a continuous forest management operation, say you have a really good pulp market and you cut it at 22, which doesn't make any sense at all, you would replant it and grow it another 22 years. So if you look at a hundred years, you have almost five rotations in there. If you waited until 50 years you would only have not quite two. So, you look at that inventory and say I want to look at this on a per acre per year basis over this time frame. What difference does it make? And it turns out it doesn't make that much difference. I think that's because of the management intensity. If you had a very low stock stand and you were trying to get that inventory to a place where you could harvest it, it would matter a lot. So I hope that helps people to understand the difference between what David is saying, because he's right the longer you let a stand grow the bigger the volume gets the bigger the trees get. But if you keep reforesting it, what this does is open up the possibilities for a whole lot of different management intensities and time periods that forest landowners manage over. Last time we had Weyerhaeuser on and we also had Port Blakely Timber. Well Port Blakely Timber, their rotation age is something between 50 and 65 years depending on where they are. They also send a lot of wood overseas since it is too big to market here. Whereas Weyerhaeuser won't really tell you but they're trying to shorten that envelope. What this says is there's lots of potential out there to manage on rotation age. We don't really need to get wrapped around the axle so much so long as the forest continues to be forest. But at that point of harvest is where you have the greatest potential for it to shift into something that isn't forest.

Mark Wishnie: I agree with that Elaine. I just wanted to make a second comment that sort of follows on that. What I talked about in my remarks is that we need to see this as a system, and I think we have all kind of touched on that. We can harvest. We can extend rotations and then shift our products. We

can shorten rotations and shift our products. We can produce more products and substitute for more things. We can produce less products and substitute for fewer things. The total carbon benefit depends not just one what happens in the forest. The other thing I think is important to keep in mind is that what we are talking about here is the interaction between the market, a demand for a product, and the systems that supply that product. Although we are talking about forest ecology and carbon accounting, that's an economic system. It's an economic decision. We can't lose sight of the fact that we can increase forest carbon stock, say by extending rotations for a long period of time, but if that decreases the value of the forest by 30%, then we've just made our forest products more expensive. And if we make our forest products more expensive, we will assume in an economic system, that we would consume less of them. It would make other materials, like concrete and steel, more appealing. It is not just a question of the carbon accounting, but it is a question of the decision actors make across the value chain. When demand increases under many circumstances, that means timberland owners start investing more in their forest. They start converting more land to their forest. When price increase builders and architects start sourcing alternative materials. When prices decrease, they start sourcing more of those materials. All these factors influence the decision making of actors across the value chain. But if we want to know the total climate impact, we have to understand the climate impact across all of those things.

I am looking at the time and this is a tremendously great discussion, but I want to allow each of you to make one final comment to the group.

Mark Wishnie: I kind of just did my summary there but these are really important discussions. It is incredibly positive to have the design community and the engineering community here asking these questions. I think we need to do two things here. One is that we need to continue to insist on sustainability in the sourcing of our materials. We need to insist that the carbon accounting adds up. The second thing we need to do is we need to recognize where the real risks actually are and where they're not and what it is we can rely on. In the US we have a pretty good starting point. We can do better but we are also starting from a place where we can have pretty good confidence in the climate impact of our material use decisions. Obviously, there is a lot of nuance there as we have covered. Let's focus on what are the sort of critical factors and not be overly concerned, but also continue to insist that we raise the bar.

Elaine Oneil: I think I want to go back to my take home message of there's a lot of levers we can pull. My talk was really focused on carbon but trying to put that back into the context of all the other things that were identified in the survey. It's not just about carbon, it's about all these other things. I think it is important for people to recognize that something as critical as say biodiversity, doesn't happen on a single acre. You can't do the same thing everywhere and expect biodiversity by definition. Biodiversity is really a landscape level assessment. When we think about how to be comfortable or what kinds of questions need to be answered in this ongoing dialogue to realize that when I'm looking at forest like this on the chart there, it's a pretty intensively managed forest. It's not going to have all those biodiversity elements in it, but the forest next to it might have, or the riparian reserve or all those other protected lands. When we think about this, we don't necessarily have to panic so much about every single stick of wood that we harvest, what's happening on that acre other than is it sustainable. But how do we place that into the larger context within the landscape and then in the larger context that Mark had identified of that global economic system.

Indroneil Ganguly: One of the things for me to emphasize is two numbers there. One that is not there in the standing biomass in the prior carpet forest. That's the 60 to 65% number. The second number I had is what the wood does outside the forest if you factor that in. That number is actually 227%. The wood outside the forest, the biomass outside the forest, is almost like steroids. Its working in storage we should optimize. And the answer for the next question there is yeah, we can do better. But we need to understand is increasing the wood stock and biomass in the forest doing better or increasing the carbon stock biomass stock in the economy and substituting for high carbon impact materials make truly a natural climate solution.

David Diaz: I'm hopeful this will come up in subsequent sessions that you are doing, based on the descriptions it looks like they might, but I think that Elaine, Indro, and Mark kind of represent a particular vision on how to calculate substitution that is not universally shared across the forest researchers. And so, there are lots of assumptions about whether we are going to burn the fossil fuels anyways. Whether that undermines the substitution effect we are claiming by avoiding fossil emissions by producing concrete and steel. There's a variety of things like that that are actively debated among scientists in this field that I think are really important. Because the combination of decision making around the social cost of carbon, how you calculate substitution effects, and market leakage effects, those alone will change your policy recommendation. There's a variety of assumptions underlying each of those that are often not unpacked because it does get really far into the weeds. I think there's a lot to go for there but like I said earlier I think in general, so long as we embrace this idea of continuous improvement there's going to be different solutions that get adopted by different types of landowners to make incremental improvements in their management and conservation approaches. We didn't even really scrape this. You know Elaine described the biodiversity interests here. Increasing carbon stocking in forests is not going to make sense in many places. When we think about places that are fire prone for example. We need to look beyond carbon as a primary indicator of sustainability that we have been using in LCAs. For example, if we actually do care about water quality and the biodiversity crisis, we can't say lets just keep piling up wood on the East side and just have catastrophic fires occurring for generations to come. That's not a smart way to manage our forests in places where we have been keeping fire out of the natural fire process for a century. I think there is going to be a need to resist this one size fits all type of thing. I'm really appreciative to have worked with a lot of innovative architects that are navigating that complexity very elegantly in terms of integrating social impact factors and environmental impact factors into their procurement decisions that go beyond carbon. Even just like prioritizing purchasing wood from Indian tribes for example. There is a lot of good work that your purchasing power can do, and I hope all of you continue down that path to find out more how to direct your purchasing power.

End of Discussion

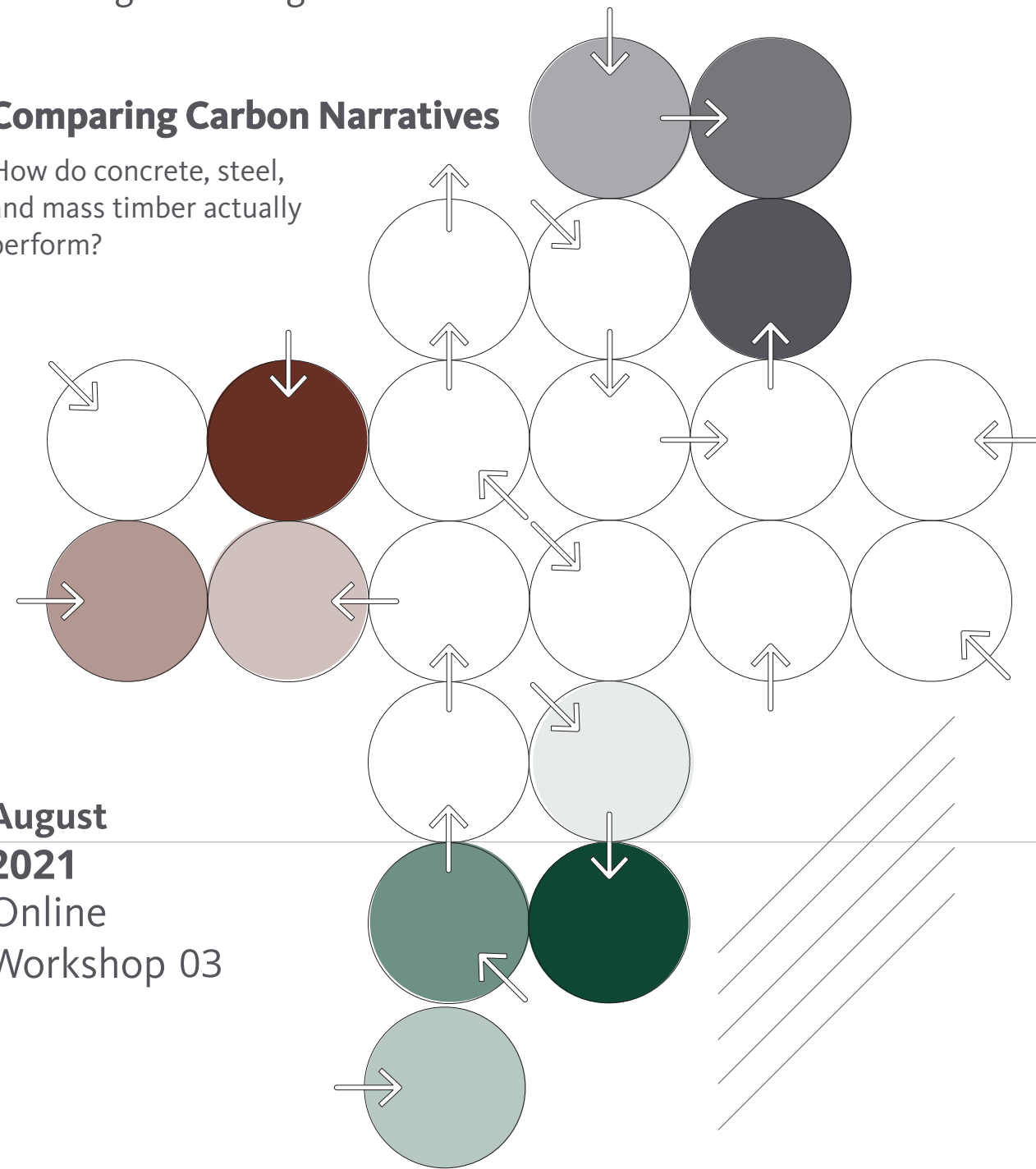
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Carbon Narratives

for Design Planning

Comparing Carbon Narratives

How do concrete, steel, and mass timber actually perform?



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Workshop 03



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Panelists

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Instructor and PhD candidate
Civil, Environmental and Architectural Engineering
Incoming co-chair of the Structural Engineering Institute (SEI) Sustainability Committee

Todd Beyreuther // Mass Timber Systems, LLC
Founder
Design Engineer

Matt Hoffman // KPFF Consulting Engineers
Structural Engineer

Question and Response

The third workshop will address the comparative carbon analysis of three common structural materials, concrete, steel, and mass timber, and will explore the complications associated with hybrid structural systems. All three industries producing these materials advocate for the use of their material to reduce carbon in the built environment, each drawing on data and assumptions to support claims. The conversations will investigate these claims across all modules of Whole Building Life Cycle Analysis to understand the at times divergent narratives of building carbon estimation. The purpose of the panel discussion is to discuss the nuances, assumptions, and missing data points with experts studying these carbon models. There will be a Q&A period following the panelist presentations.

1. I will start with the question at the top. It looks like this is mostly for Matt, so I have heard that steel is infinitely recyclable, and as Matt pointed out electric arc furnaces use mostly recycled steel, why then do we still find mostly blast furnaces? Is there not enough steel to be recycled or does steel lose its properties the more times it is recycled?

Matt Hoffman: Steel is an infinity recyclable material, however in the electric arc furnace when all the scrap metal is combined, you do lose some of the purities for certain types of steel grades, like stainless steel for instance. The holy grail of producing quality steel is being able to produce the exterior automotive sheet steel that they use for cars. This is challenging to do in an electric arc furnace which has a limited capacity to produce high-quality steel at this point. The technology is emerging where they are adding more raw materials to electric arc furnaces in addition to the scrap metal to kind of bring the quality of steel up and to create different grades. It is not raw material I should say, it's the raw iron but that does come from a blast furnace. While that does eliminate the basic oxygen furnace step, it still requires that iron is created in a blast furnace. The blast furnace basic oxygen plants are enormous. They were created a hundred years ago, and they are just these behemoths that have this economy of scale that's challenging to compete with. They create cheap steel that is high quality and it's cost effective to buy from them. The electric arc furnace industry, they call them mini mills that use these electric arc furnaces, there are several of them all over the country that are recycling steel. They often build them near scrap yards, so they have readily available material. They are developing processes in which they can develop higher grades of steel. But from a structural perspective, almost all steel is recycled. Eighty percent of the steel used in structures is rolled shapes

and those are all from electric arc furnaces. Fifteen percent is HSS. One of the reasons that HSS usually comes from these larger plants that use blast furnace and basic oxygen furnace integrated processes, is that it takes a secondary rolling process to create HSS, metal deck, and steel studs that just isn't built into the infrastructure of the other mills. So, it's less of the production process and more just the post processing capabilities of the mills. Five percent in a building is a plate product which can really come from either the electric arc furnace or a basic oxygen furnace. Hopefully as technology develops, we will move even further away from the basic oxygen furnace than we already have. Again, in the United States about 40% of the steel comes from the basic oxygen furnace as compared to 70% worldwide. We are the leader in clean steel in the world right now and we are moving ever more in that direction.

Jay Arehart: I'll add on to that. The retirement of our building stock isn't quite keeping up with the demand of our new construction. So there just isn't necessarily the full supply at the macro scale, which is good in that our buildings are lasting longer than we want them to or than they were originally designed for. If we can avoid building at all that is probably the better option.

2. Is there publicly available data that shows the distribution of greenhouse gas emissions for cement production or publicly available LCA data?

Jay Arehart: Yes, the International Energy Agency Cement Technology Roadmap does a good job of outlining this variability. The Embodied Carbon Calculator tool from Building Transparency should be having this coming out soon. I have been talking with the person working on that so these numbers should be coming out soon, specifically the US but you can find some of those in the AIA report.

3. Does concrete carbonation happen underground, in foundations or landfills for example, or only through exposure to the atmosphere?

Jay Arehart: Yes and no, to a lesser extent. There is carbon dioxide in the air so where your concrete is exposed to air it will carbonate. Some people have discussed the idea that in substructure there is carbon dioxide that is dissolved into some of the pore water that enters in, so some carbonation occurs. The research isn't sure about all that yet. There isn't consensus. The conservative assumption is to only be considering your exposed concrete, ignoring substructure and anything subgrade.

4. How does this concrete carbonation compare to the carbon sequestration potential of wood?

Jay Arehart: We could probably talk for a half hour on this one. I'll let Todd start.

Todd Beyreuther: No no I was going to punt because first of all Jay is far more qualified but there are previous panelists and others on this call that can really speak to this.

Jay Arehart: Okay so my take on this is that when you sequester carbon dioxide into your concrete, the only way it is going to get out of your concrete again is if you heat it up to that fifteen hundred degrees centigrade. The likelihood of that happening is very very low. We can think of the carbon sequestration in concrete to be sequestered and not just temporarily stored. Whereas in a biobased product, your mass timber, your wood, or really anything, that carbon is temporarily stored and most likely at the end of life it

is not going to be stored forever. So, with that it really gets into the question of functional equivalency and what you are trying to look at. It is very difficult to make a functional comparison without looking more in depth. As a gut check for yourself, the carbon sequestration from concrete isn't super significant and on a much smaller scale than what you are going to get with your timber, but be careful with your accounting techniques. Use dynamic accounting techniques to really answer that question well.

Todd Beyreuther: Yeah, I see another question coming up here about certifications and so forth. I think just as a general statement there are deep experts in this area. But my common question across the entire value chain is what kind of accounting specification is appropriate at the building project scale versus driving innovation and those concepts upstream. That is pivoting away from the question a little bit but its also pushing a little more responsibility and design intent up the value chain so we can offer better products.

5. Does concrete carbonation occur in concealed conditions such as directly behind a gypsum partition?

Jay Arehart: Yes, it does. It can even occur through paint but to a lesser extent. There are some reduction factors to apply to account for it being covered.

6. During the construction process who actually knows where the cement is coming from? Who chases this information on the project?

Matt Hoffman: It would be the contractor. The ready-mix producer themselves would source their cement, usually from a particular source. Sometimes in a local region they can be from the same source. In general, how clean the cement is should be reflected in the Environmental Product Declaration for the different concrete mixes. If the cement source for locality affects the overall global warming potential or carbon content of ready mixed concrete for that area, then I guess that is something we should care about. However, it is kind of challenging to move the needle on that one without asking ready mix producers to do business elsewhere. It is not really feasible from a design team standpoint. We can specify lower carbon concrete, but if local ready-mix suppliers can't produce it then ultimately won't be part of the project.

7. Here is a question for Todd. Talking about advocating for certifications, within that push to drive for certification are you looking at those certifications, FSC for example, to reevaluate what they are measuring to optimize sequestered carbon across the product, timber field, forest, and the soil?

Todd Beyreuther: It's a good question for experts such as Dr. Elaine Oneil on this call. What I would advocate for is not necessarily any one certification, but rather how do we bring that transparency and that influence up to that level, up to the soil science and the manufacturing process. That's been a ten-year question for many of us in this field. Is it appropriate from a demand pull versus actual investment and value systems up stream. I know that is a hard topic when we are practitioners and the levers that are available to us can be somewhat limited and frustrating.

We spend a lot of time understanding existing supply chains as is rather than really using our skills as designers to imagine what they ought to be. I really commend Jay and the team at Boulder he touched on some very important topics. They are opening a whole new world in these fields on where it should

go and where it can go. If there are students and others on this call, really advocating to push up stream. There are great opportunities at UO and OSU and elsewhere.

8. Would similar embodied carbon reduction strategies apply to steel reinforcement and concrete or any other recommendations for reducing impact of rebar?

Matt Hoffman: We have found at least locally that reinforced rebar is highly variable on how clean it is. There are some local producers that have very dirty steel. It can actually be from a carbon standpoint that it might not cost the project much more but it might be a huge savings in carbon realized from sourcing steel from maybe the Seattle area or something. Not so say some local producers don't make clean reinforcing, but just as an example it's not that much more costly from a project dollars perspective to ship in reinforcing steel that is lower carbon. I guess what I'm getting at is it's highly variable in how clean it is. As far as how can we reduce reinforcing steel's impact, don't over reinforce concrete. The American Concrete Institute has some minimum reinforcing requirements that have to be met. As designers and structural engineers, we just need to make sure we are as efficient as we can be with reinforcing and only use it where it is necessary. Add a couple more footings in your footing schedule rather than designing for worst case all the time.

9. So, I understand that concrete is sometimes recyclable but have never really understood to what extent that is possible. How can it be recycled and used in other products and is it worth the energy?

Jay Arehart: We often hear about recycled aggregate concretes. We can take our concrete that's being retried, crush it up and it can be used as an aggregate. There are a lot of durability concerns that come with that though. One is once you have exposed your concrete to chlorides, so deicing salts or if you are in a marine condition or close to the coast, you have lots of chlorides. And that spells a disaster potentially for using those aggregates in new infrastructure. So, where we primarily see concrete aggregate used now a days is road base. Underneath roads you need a base layer and so that's where recycled aggregates are finding a home. Really the best end of life strategy to do is to crush up your concrete, leave it exposed to carbon dioxide, preferably in a high concentration environment, and have it be there for a couple years. Then have it enter a subgrade environment. That is kind of the optimal end of life strategy right now from the durability perspective of a new product as well as maximizing the amount of new sequestration you get out of it.

Matt Hoffman: I would add that in order to produce aggregate to be used in concrete, it has to be precisely milled to a particular sieve size. That in of itself can come with a high energy demand in order to process the recycled concrete down into that level and precision. So, you may lose some of the benefit of recycling the concrete in the process and effort.

Jay Arehart: I will add too that when you are using it as aggregate, you are still producing more cement to add to it. It is not just a direct reuse; you also need to bring cement in so that you are just replacing the aggregate of your concrete.

10. Another question for Jay, I'm curious about on of your diagrams. The last piece about sequestered emissions verses in the atmosphere, what is the timeline on that?

Jay Arehart: Yeah so, I glossed over that because it is quite a nuanced answer.

It is since the beginning of cement production so around 1900 to 2013 is where those numbers are from. I'm happy to share the paper where that came from.

11. We will switch back to carbon storage in timber for Todd. A few panelists in the Carbon Leadership Forum wood series pointed to the US EPA data estimating that 88% of lumber carbon may be stored permanently in the landfill. Do any of the panelists have any information on the validity of this and is this reasonable to make assumptions based on this while using the LCA?

Todd Beyreuther: I am not an LCA expert so I wouldn't challenge CLF or others, although I would ask what the real question is here. This is really an end-of-life discussion or longevity, resiliency, and so forth. I think in that context from a design standpoint we are not yet at a maturity in timber design that we are finding the optimization in the right place. We often think, and I am an engineer, that it is about efficiency in the structure and that is going to lead to cost and savings and efficiency. But really I think when you dig deeper into the entire value chain, the scale can quickly outrun the cost on the project. Which shifts our minds more toward longevity and value of that longevity across the entire life of the building. That does not answer the question directly so I will throw it over to Jay or Matt or others if they want to talk more LCA.

Jay Arehart: When you are making comparisons between decisions it's important to be using a consistent life cycle inventory. The life cycle inventory that you are using is going to have a series of end-of-life assumptions that is informed by data. As a designer in 2021, we are not going to know what's going to happen to our building in 70 years or 90 years. There is uncertainty around that. Thinking through instead of saying 88% of the carbon is going to be kept in the landfill in timber, I think a better more informed approach would be to take a scenario approach. What if all the carbon is released? What if 88% is released? Using a scenario framework for evaluating different decisions and then having that inform the decisions you then pull from your life cycle assessment. Remember life cycle assessment is a tool not the end all. That is sort of my take on that, happy to elaborate if you want more nuance.

Matt Hoffman: Yeah honestly I don't feel like I can offer anything more to the timber end of life discussion. I think Jay's point was a good one.

12. Here is a question for Matt. They are curious about the 28-to-56-day straight spec. I have heard this one before but it was recently mentioned that we get meaningful strength at seven days, so what is the rule of thumb again in reducing carbon in cement?

Matt Hoffman: Concrete gains strength quickly early on after it has been poured. The strength curve is really steep early on in concrete's life and then it flattens as time goes on. So you are right in that high strengths are realized early on right after a mix is poured. Historically before we started thinking about why we are putting so much cement in our concrete mixes, we were actually reaching design strengths in seven days or even fewer sometimes for elements that didn't really require that quick of a strength gain. In an effort to reduce the cement, we can start targeting strength further along in that curve and we can use less cement to achieve that strength, provided we can wait long enough to get out to that point on the curve for the concrete to get to that point. We are trying to put it on the concrete mix designers. The ones that work for the ready-mix producers that develop mixes that still meet the strength characteristics required for the design, but that can use less cement and get there in a longer time frame. It is more challenging and puts

a little more risk on the contractor and the ready-mix supplier, so they don't often willingly go that route. In some cases, ready-mix producers and cement manufacturers are one in the same. They really don't mind throwing a lot of cement in their concrete mixtures because they are buying it from themselves. It doesn't cost them a lot. As part of our specifications we need to control that by specifying low carbon concrete. Having said all that, the 56 day approach is great but it does carry real schedule impacts. For fast-track projects it's really challenging for contractors to work into their schedules. There are some components such as post tensioned slabs, elevated concrete beams, or cast in place monolithic slabs that are elevated that require a quick turn around and strength gain in order to keep the contractor moving onto the next level of the structure. So that is a consideration too.

13. Shifting the conversation back to steel, I've heard that steel sourcing is very difficult to control right now so is it realistic to specify large steel members with lower GWP impact at this time? What changes need to be made to make cleaner steel more accessible?

Matt Hoffman: That kind of goes back to the emerging technologies of these mini mills and electric arc furnace producers. I'm not sure why a large shape wouldn't be available from an electric arc furnace producer if it's a rolled shape. But my suspicion is that the larger rolled shapes just take a level of infrastructure that isn't present in these mini mill scenarios and that would require one of the larger mills to roll. I would also suspect that if it is a higher grade of steel that an electric arc furnace mini mill might not be able to meet that ASTM of that high grade and it may need to be sourced from a virgin steel producer. In terms of the second question, we can try specifying more efficient shapes and shapes that are available. We can do our research to see if what we are specifying is available from mini mill electric arc furnace producers and that doesn't require virgin steel. Hopefully as time goes on technology continues to develop and producers realize that there is a benefit to them investing larger infrastructure to accommodate the demands.

14. In continuing that, what percentage of structural steel is sourced from offshore markets? How is it possible to examine and quantify the environmental performances of these international supply chains and production processes?

Matt Hoffman: I am not sure of the exact percentage I think it's pretty high though. I want to say it's around half of the steel we use in buildings. I have read the United States produces enough steel to supply the entire building industry, but we don't buy it all domestically because of the cost. International steel does develop EPDs so there is that information available on how clean the steel we are getting from over seas is. That is something that can be quantified and would need to be considered if there is a carbon limit placed on the steel for a project. But again because of the cost savings it might be prohibitive for the owner to want to consider putting a limit on the GWP such that it has to be domestic steel because of the cost increase. We are seeing a lot these days that specifications in projects are requiring US steel. Which is great because right out of the gate it puts us at a benefit at an environmental standpoint.

15. Do any of the panelists have experience with the Delta beam, which is a hollow metal beam that gets filled in with concrete and has the capacity to reduce floor assembly depth? Are there trade-offs like the ability to recycle the materials at the end of life or other global warming impacts?

Matt Hoffman: I have not. I have heard of Delta beams and am familiar with

what they are but honestly, I have not used them in practice. They do seem like a good product, but I have not used them, and I really don't know much about them other than just being able to quantify the materials they are made of. I think there would be some amount of consideration of the construction of the hybrid system and how much energy goes into that process. It could be that since it is done in a factory or a shop and brought out to the site that it could be something that is fairly efficient from an energy standpoint.

Todd Beyreuther: It's an interesting proprietary system but I think in general what we're seeing when we started with hybrid with timber for example, is a move in Europe in particular to these flatter precast beams and columns mainly for cost. But really from a more tectonic standpoint as we think about our ability to really control the stiffness of those beams and use a non-combustible material such as concrete. Again, Delta beam is of steel and so forth, but it really is of the same premise that we can achieve our fire resistance ratings with that beam. I think we will see that North America a little more use of flat, inverted T, precast beams with the ion on the cement carbon reduction that is being discussed today in addition to having timber floorplates. I'm excited about that area and these two-houred structures.

16. In Portland, the Oregon market, is it easy to achieve 40% slag currently or would 40% concrete typically be cost neutral or provide cost savings for the project?

Matt Hoffman: Yes, we can achieve up to 40% slag in our mix designs. There are a few things you need to consider when that happens. You do get a slower early strength when you use high supplementary cementitious materials in concrete. A high SCM mix would really only be applicable to certain concrete elements, foundations are really good ones, slabs on grade, columns can even have that. For multistory structure, the base column is only seeing a small fraction of its eventual load. As the building goes up it gets more and more of its design demand, but that could take a while. As far as slabs go, we have found this to be the case on most of our mixes that use high SCMs, contractors seem to have a hard time finishing the surfaces. I don't know if it is something they are just not used to and haven't gotten good at yet or if it's a real problem. They often call them "sticky mixes." They have a hard time getting a real flat floor finish. We've also seen some cracking issues with some of the high SCM mixes as well. Where architects say this is great, lots of supplementary cementitious material, low carbon concrete, but wait a minute what's going on with the cracking? Why'd we do this again? So yeah, there are some concerns. But yes 40% mixes are definitely possible.

17. If any panelists have any key takeaways from their presentation or any last thoughts that you would like to share with us as designers on this call you are welcome to now.

Jay Arehart: One that I think we just touched on a little bit with the couple last questions is this idea of functional equivalency. There's not an easy answer with any of these. Steel is not better than concrete, it's not better than mass timber, than all the hybrids within that. If you take one thing away from this is doing your own life cycle assessment and making it a whole building life cycle assessment that covers all the different life cycle stages, that's key to actually making informed decisions. It takes time. It takes effort. Working that into your workflow and figuring out ways in which you can do small studies in which you can say okay this is a typical bay and working through that. Just the question of well is this floor slab better or worse than another one. Well, if you are going to get a lower depth then you are going to have to take into account different column heights, and that's going to affect lots of different things. There's not

going to be an easy answer. That is my takeaway, really get into the idea of functional equivalency and make sure you are defining that whenever you are doing analysis.

Todd Beyreuther: A couple summary thoughts here, I'm very excited where we are going across the materials. I feel, especially in the timber front, we are getting away from this wood is good as a selling point and now we can have a larger discussion about both hybrid systems structural and architectural but also normalizing more across the materials. It reminds me of five or six years ago when I first met Jay's colleague, Will Schubarrow, at a Carbon Leadership Forum. It was finally a kind of offline conversation between steel, concrete, and wood saying lets really just cut this down. What are the synergies here if we really get away from our defensive position by material. We started to get into this larger discussion and of course the forum was about carbon, but it really started to come to these prefabricated solutions. Back to this idea of where are the levers in this system, in my opinion it's going to be in this secondary design of assemblies and so forth. Where we as designers not only have a little more control of specification but also of how we bring these solutions together. The further and further away we get from the commodity materials and I'm not giving criticism necessarily of the use of mature materials such as steel and concrete that includes wood also. That includes lumber as a commodity. We have just experienced it this year of how out of control that pricing can get. It was never about scarcity of material; it was about other factors. Anyway, my advice is the closer we can get as designers to bringing our thoughts on carbon and structures together it's going to be exciting. I really encourage that, thank you.

Matt Hoffman: What I want to see continue with the design community is, you know it's great we are having these discussions, starting to able to implement some real world and real project restrictions on global warming potential. That's awesome. But really it's only so far been for concrete. One of the reasons for that is it is kind of a low hanging fruit. It's really easy to control concrete mix designs. There's so many different versions out there and so many different suppliers. As we get a better understanding of steel and especially, I think the big unknown is the timber industry and the impacts of timber, forestry practices, and everything that contributes to that. As that gets more understood, just trying to incorporate all these materials. Putting a cap on everything and controlling the embodied carbon in our structures, before it gets released to the contractor knowing what it's going to be and being able to control that. We are not there yet but I hope we continue to have these conversations, develop case studies for projects that are being constructed right now, and get a better understanding of the built environment that we are creating right now and will in the future.

End of Discussion

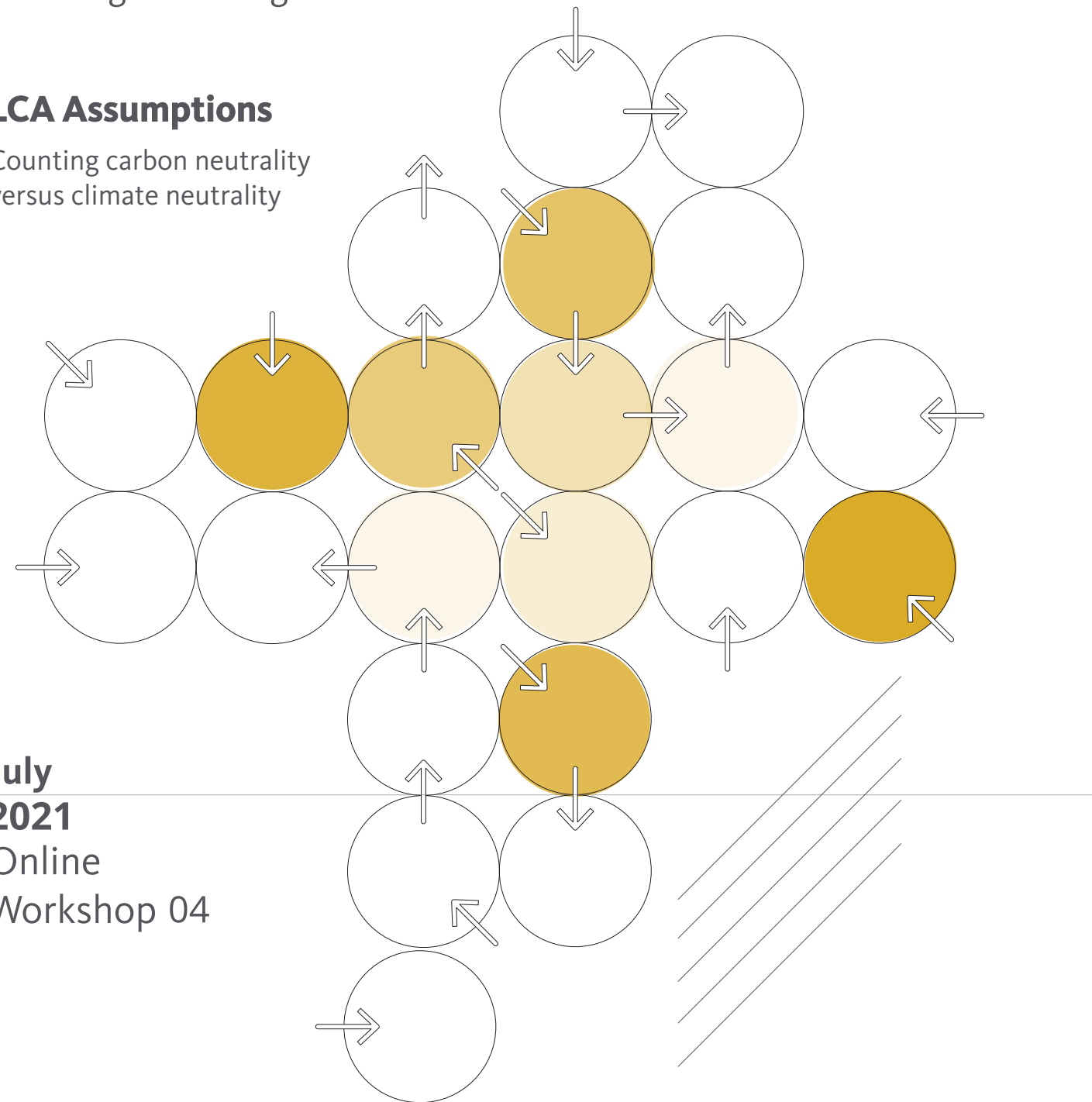
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Carbon Narratives

for Design Planning

LCA Assumptions

Counting carbon neutrality versus climate neutrality



July
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Online
Workshop 04



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Panelists

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Natural Resource Specialist

Adam Robertson // Sustainatree
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James Salazar // Coldstream Consulting
Principal

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Director of Operations

Question and Response

The fourth workshop in the series will center around lesser understood topics of Life Cycle Analysis that often provides an incomplete picture on global warming potential. There are assumptions made within LCA that do not consider regional differences or only look at a portion of the life cycle of the material leading to results that provide a short-term solution. The panelists will explain these lesser understood topics and the conversations will explore the time scales of carbon and climate neutrality.

1. First question for our panelists, have any of the families found a good method or tools to quantify retrofits in comparison to new construction for LCA? Clearly the retrofit would use less embodied energy almost every time, but quantifying that savings is currently a challenge for our firm so thoughts on that.

James Salazar: Yeah, I know that when you are talking about retrofitting versus whole building and embodied impacts of a new construction, it's really following the same tools and methods that you are doing for whole building LCA in the first place. I know Athena has been involved in the past for exactly that question. Considering the tradeoffs of let's say energy performance of a new building versus retrofitting an old building. That's kind of a classical LCA question. I would say that any of the whole building LCA tools that are out there, as long as you are defining your two systems adequately in that software, that would give you something reasonable to look at.

2. I guess to follow up on that with another question if you don't account for everything in the LCA, particularly a whole building LCA, such as embodied energy basics, how might the results mislead us? That's one of the narratives we hear, is that could be a big contributor and it doesn't get accounted for.

James Salazar: You are certainly right on that. I think that embodied energy and embodied impacts and energy simulation are completed in silos and maybe not as much overlap and integrated analysis. They are certainly something we are working on now; it is actually one of the reasons we founded this BAS carbon that's partnered with a couple of really talented energy modelers optimizing envelope design and that sort of thing. Then looking at that exact question of embodied impacts, tradeoffs versus energy performance in some kind of unified reporting where you are actually looking at those side by side.

3. Do any of you have comments on the Katerra story relative to LCA? I think that is probably about that idea of vertical integration to be able to understand all components. Was it a success or do you think that model could have been a success, in terms of LCA even if it wasn't a business model?

James Salazar: I will let others talk on that but what I can say is I was very disappointed. We were lined up to do an EPD for them the week that they folded. As far as the business case of the vertical integration, I think others are probably better to speak to that.

4. I am just thinking in the actual LCA case. In terms of accessing data or the data you might think is missing, how would vertically integrating operations be able to get you data that you might not otherwise have clarity on?

James Salazar: Definitely, in that case we have done a few of those too. Where you have full access, very specific data upstream rather than pulling off of industry average type work. I would say in that particular industry there is not huge variation in let's say lumber suppliers into mass timber. But being very specific is what we are seeing really the demands for information from LCAs as you want material supply chains as specific as you can get.

5. I am going to go down again and talk about existing buildings which is on all of our minds too and this idea of reuse. As our built environment continues to expand, we know by UN population estimates, I think by 2060 we will be doubling our current building stock, so if an individual building is determined good for the current carbon crisis is it still considered a good strategy when scaled up to the size of the anticipated building stock? What should designers prioritize to both reduce short term emissions and long-term emissions?

Martin Brown: I don't know. I don't have a good answer, let other people talk. These are really difficult questions. As Maureen pointed out in her presentation.

Martin Brown: I guess I kind of suggests that if there are going to be more buildings, use phase emissions are still important even though we are talking about embodied a lot now.

James Salazar: One comment I can make on scaling up, you know LCA is very linear when you are talking about the average impacts of a particular product. When you scale up to building stock type analysis, then you get into a field of what you call consequential LCA. It is better designed for policy type questions like major industry shift and things because now you are talking about supply availability and not just looking at average but what happens at the margin. If you were to scale up let's, say forest production by 50 or 100% to meet the kinds of demands for mass timber projections around that. You do run into supply chain limitations. Just because something has an impact on the average now, it would not necessarily continue if you made a major shift in industry. It tends to veer more into the economic type analysis and overlap with that where you are looking at major shifts in industries and how they are managing upticks and major scale changes like that.

6. Do any of the panelists have suggestions of how to quantify embodied carbon across different parts of the world given the vast differences in environmental laws in different countries?

Maureen Puettmann: When we do LCA, and I've done some for other countries, we do use different impact methods that are applicable to that country. They will have different characterization factors for each of the green house gas emissions for example. Basically, from there it's data that's incorporating their forestry models, their wood production, and all their fuel uses that are produced for that country in particular. We can adapt to that. I don't know how other agencies can do that, but we can make those adjustments.

7. I don't know who asked that question, but if you have a follow up please jump in. Here's another one that I think is interesting. Given the industry, and I'm assuming AEC industry, is frankly still struggling even to adopt basic LCA approaches, is going to dynamic LCA or GWP Bio worth the extra effort? Will they drive a fundamentally different decision outcome that makes significant difference in the more immediate climate crisis that we are facing?

James Salazar: I think I sort of touched on that in my presentation a little bit. I think that those are super useful tools and what I am more interested in is finding a middle ground between something we know is important. The scale is clearly important, the timing generally is important. But is there a way to take it out of a super detailed research tool like that and put it into a handful two or three GWP metrics where you could quantify that and make it more feasible.

Martin Brown: Well actually I think all the work that goes into anything like this kind of reflects my main point. I am an analytical person; I like to be involved in these games about calculating things. Ultimately at the end of the day the biggest question in terms of environmental impact is, should this thing we are working on be created? That completely overwhelms lots of the differences between our calculations.

8. So, Martin I'm going to follow up with you with another question. This one is directed at you. Given your very relevant comments on how we utilize and focus our LCA studies, is there a strategy or focus you might suggest relative to our evaluation of woods role in our projects that maximizes its impact besides just producing rationalizations for that third vacation home? What should we be thinking about to get closer to that thin green line that you just described that we are drifting away from?

Martin Brown: This is the big answer, what kind of definition of a good life are we really working towards? Once we know what a good life is, then we can start doing policies and making buildings that allow people to live those good lives with lower consumption. I think architects are perfect for this because in my own life I have discovered that good design can help me live a good life without a lot of consumption. I think that is the ultimate answer.

9. This is about Maureen's study stating that transportation from Northeast to Southeast accounted for 10% increase in GWP, manufacturing, and transportation. It contradicts similar studies, LCA and I believe CLF studies that state, transportation is typically less than 5% of total GWP. Does this align with other analysis, any idea why transportation impacts were so high?

Maureen Puettmann: That's a very good question. This goes back to a little bit what Martin covered and that was functional unit. The CLF data or the EC₃ data that has the transportation in there is A₂. That is all based on a cubic meter. When we do our LC studies on a cubic meter transportation A₂, for

those of you that know about the modules that's transportation of resources to production, is usually less than 5%. What I showed was A4. That is taking the mass timber and the glulam and the quantity of the mass timber and glulam that go into an eight-story building. That is a lot of wood. When you are transporting that product, all that wood product from the Northeast to the Southeast, it did raise the GWP by 10%. It was a combination of mass being transported and the distance.

10. Here is a follow up for you, what assumptions were made about shipping timber to the site? Do you know whether those considerations include any information about forest management? Once wood is dried and milled, it is my understanding that shipping from supplier to site was not such a great impact relative to the others. If a project would like to use timber, but does not have sustainably produced timber available locally, would it be realistic for that project to consider procuring the timber from a greater distance over land or water?

Maureen Puettmann: Again, to follow up on what I just said, so yes once the wood is dried and you are looking at just on a volume basis being transported a mile, that's how it is reported in the EPD and it is very small. Again, it all has to do with how much wood is in that building. I don't know if anyone has really looked at the difference between the mass in a light frame construction of wood and the mass in an equivalent height building in let's say a single-story residential home built with timber frame versus mass timber. There is a heck of a lot more wood in that mass timber building. All that wood had to be produced and it had to be transported. In relationship to production, yes transportation is a lot less. But in the situation I showed, the production stayed the same in the Northeast, but we transported it quite a large distance in order to put it in a Southeast building. Obviously that wasn't the best scenario because the Southeast is the only region in all those studies that actually had production sites of CLT and glulam. It was the only one that wasn't hypothetical or an average of different mass timber production facilities. The Northeast was completely hypothetical at the time. If you go to transport a large mass of material, you are also producing that large mass of material. That relationship would stay the same. I am just saying in this case we transported it so far and it was a lot of material. There is a lot of material in a mass timber building.

11. Terrific thank you for that response. Can anyone recommend sources beyond Semipro for understanding A4 and A5 impacts?

Maureen Puettmann: I don't know the other softwares and how transparent they are so I can't answer that.

James Salazar: I can say that Athena software and also Tally, it's laden with lots of assumptions and a bit of a black box. I can speak for Athena software because I am involved right now and the update for that. Essentially our motto is we are taking the training wheels off and it will be fully parameterized. You can be very specific moving forward this year. Yeah that is certainly an issue and it definitely relates to massive products like mass timber. It makes a difference whether it is five miles 500 miles or let's say 50 miles. In the past where a lot of this was driven by industry level work, now we are getting more into very supply chain specific. The ability to model that is critical. I know there are some resources on transportation type calculators that are stand alone. But again, if you are doing the rest of your analysis in a whole building software and you want to make that distinction, I would say to look at the software that show the breakdown of what we call A4, the transportation to the site. Then just substitute your own numbers. They are not fully integrated

into that software but certainly in Athena moving forward one of our big objectives moving forward is to allow our users to do that.

12. When we look at global projected building demand over the next 30-40 years, how much of that demand can sustainably grown and harvested wood realistically support? To Marin's point, do we need to adjust demand to match supply? Wood is often presented as a miracle cure for the built environment but there are obviously limits to our gluttony regardless of material. Any response to the limits of scale?

Maureen Puettmann: I don't have the latest numbers, but I just got word that the Mass Timber Handbook is free to everybody online. I don't know what it is called. It is the one by the Beck Group, given out to everyone registered to the mass timber conference. They have the latest statistics. Their 2019 report, just to put it into perspective, the mass timber in 2019, which I know it has changed quite a bit, the amount of timber that went into mass timber was 1% of the lumber market. This looks like it's huge right now and frightening from a sustainability level, but it's very tiny in the sense of the amount of lumber that goes into it verse the amount of lumber that is produced for our normal consumption purposes. But that number is updated in the handbook. I can't think of the name of it right now. It's online and free but very cumbersome with my system to go through. Mass Timber Report, there someone found it.

13. Here's one for James, we are going to talk about concrete carbonation in our next session, but just based on what you showed with the graph is the phenomenon of carbonation from concrete big enough to completely reverse the current push to create lower carbon types of concrete? That is, should we stop worrying so much about concrete and work on something else?

James Salazar: I would say no on that. There's many parameters and variables in making these calculations. With uncertainly around future end of life treatment right now there's no legislation that requires concrete to be crushed unless exposed to the atmosphere to make these reversals. It's a possibility but under current practice with buildings you are talking maybe 10 to 15 max 20% depending on the application. Pavement is quite a bit more than that because there is so much exposure. I think that is a huge opportunity if you were to require it to be crushed. That is how the process happens, with surface area exposure. With no requirements solid around that, you definitely want to be doing what you can with the embodied impacts of the material. Minimizing our emissions now with the time sensitivity of the climate crisis is really important to consider. I think it is another tool I the tool box to mitigate carbon that is there currently in the building stock and to take that into consideration for whole building LCA.

14. This is for all our panelists, since many people in policy or otherwise are just still beginning to learn about embodied carbon and LCA, can you imagine broader adoption of ideas like impacts over time, variability, and uncertainty? I feel that over simplifying impacts leaves us more susceptible to greenwashing and wonder whether people could learn to think in this way if the language were introduced upfront.

James Salazar: I think that it's going to be a middle ground. We've been involved personally in LCA for 15 years. The Athena Institute has been around for 25 years, and we are just now seeing significant uptake of embodied carbon as a concept at policy levels. To then take the next step and add another layer of complexity, I think it's really great and if you are modeling reality, it is scientific these types of LCAs. I think the next step is to take that and

consolidate that into something that we can communicate better. I think that's critical of the adoption of these types of things.

Maureen Puettmann: I'll just tag onto that. I think trust is a big concern here. I know there is a lot of discussion that oh that is industry driven therefore it's going to be biased towards a particular industry. I think it's trust in the transparency of what is reported, everything shown a source around the assumptions. I think the more that is revealed of what goes into the black box, the more trust people are going to have in those numbers that the user wants. If you want a single number for a building of what that embodied carbon was to produce that building, then it's full transparency and trust on who did it and how it was modeled. The standards that we are held to make them a little more integrated. I believe we had concrete people on our wood products PCR. There is a little oversight there from a different industry on how we are required to report our results.

Martin Brown: I have a little bit on that question. I definitely think there are some encouraging signs, like we are adopting EPDs in government purchasing and stuff like that is happening in Portland and Oregon. I know it is an oversimplification but at least it is starting to be incorporated. I think there is a really interesting aspect of this that I just read about in a book called "The Power of Habit." Basically, it said that it is really difficult for people to think analytically all the time so we tend to fall into habits. So just by exposing people to this perspective, we're getting them into it, especially if they can try it. There is some evidence from this sort of neighborhood residential contractor point of view that if they are forced to practice doing something a better way, eventually they will just do it in all their work because they have gotten used to it. We are not going to make everybody into an LCA practitioner, but if we can get them into good habits a lot of progress can be made.

15. We have time for one quick last question here. I know we have been talking about carbon, this is Carbon Narratives for Design Planning, but this question is asking if anyone is aware of research exploring the proportion of impacts beyond GWP that the built environment is responsible for. We know that the built environment is responsible for a significant amount of global greenhouse gas emissions, but I am trying to understand the extent to which the built environment is responsible for impacts like acidification, nutrification, smog inflammation, etcetera.

Maureen Puettmann: I haven't been involved with the proportion of the built environment on those on a global scale, but the Nature Conservancy study that I presented data for we do report and discuss the different impacts in that study in comparison to the mass timber and concrete building. So it is in there, but as far as the contribution of those impacts on the total built environment like we know for carbon, I'm have not looked into if that's available.

Martin Brown: Comparing industries like comparing commodities is one of the places where you can't use the kind of LCA that we have been talking about today. The functional units aren't the same. You can study this sort of thing and when you hear these sorts of results they probably come from an environmentally extended input-output model. The US EPA is working on a new one that should be quite good called USEEIO. Some of those environmentally extended input-output models have more than one impact category. They will have things like water use, nutrification, etcetera. You could get those kinds of results from those types of models. They would be usually very large scale in the way they present results. So would be what you are looking for.

16. Any final thoughts from our panelists on LCA for this group of design professionals and thinking about the assumptions for how we use it and should be using it? I want to let you all have any final comments here before we wrap up.

Martin Brown: I don't know. I would say just think about whether stuff needs to be consumed and how that really makes people's lives better.

James Salazar: I'd say all the research that is going on is super exciting, and again we just have to balance this with what people can reasonably understand and incorporate into something that's actually going to make a difference.

Maureen Puettmann: Yeah and ask questions. If you are confused about a number or a result, ask questions to find out what is behind that number because most likely someone knows.

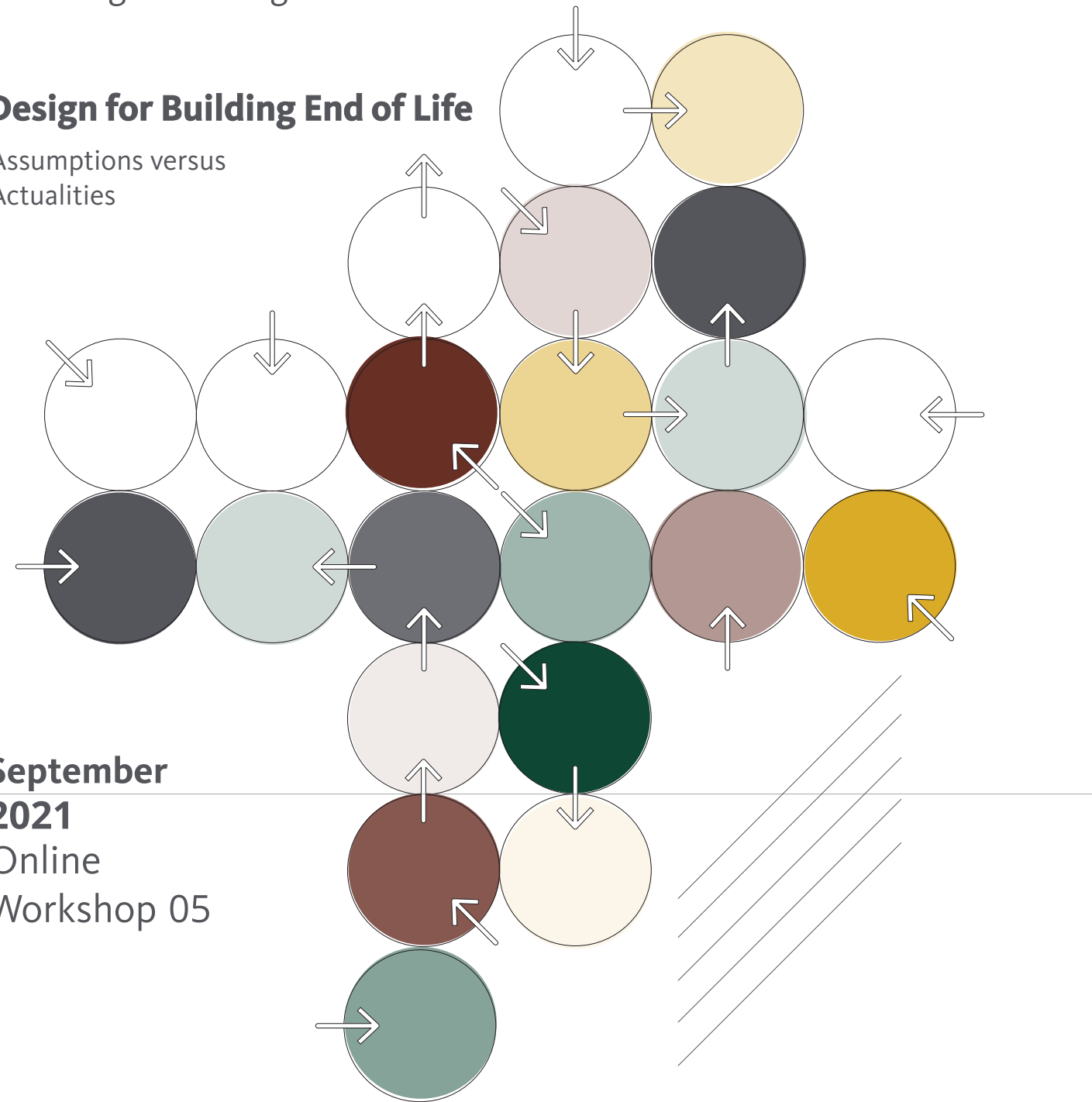
End of Discussion

Carbon Narratives

for Design Planning

Design for Building End of Life

Assumptions versus Actualities



September
2021
Online
Workshop 05



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Panelists

George Berghorn // Michigan State University
Assistant Professor of Construction Management
School of Planning, Design & Construction
Adjunct Assistant Professor of Forestry

Gilli Hobbs // Reusefully Ltd, UK & France
Co-founder
Sustainability and Circular Economy Advisor

Jordan Palmeri // Oregon Department of Environmental Quality
Senior Policy Analyst
Materials Management Program

Question and Response

The final workshop will explore the topic of designing for a building's end of life material flows. Frequently, only cradle to gate is considered when selecting a building material for its carbon content; however, WBLCA carbon content depends upon the longevity of a material, a building and an uncertain future. Concrete, steel and mass timber structural systems all claim recyclability and re-use potential but these are impacted by initial design considerations and market forces. The panel will consist of researchers and practitioners working to shape future material pathways through decisions made at the outset of a project and also bring together European and North American perspectives.

1. Let's go back to George's presentation. George you mentioned a material bank, how do we connect designers to these supplies and what about contractors that are less willing to reuse a material?

George Berghorn: That's a great question and it's something that in the Midwest we have seen varying approaches to that. Some of the more successful approaches that we've seen locally within Michigan, like Detroit area is more or less an online catalog of materials that are available from some reuse outlets. One of our concerns again has been if we start thinking about getting this up to scale, it's really difficult and cumbersome. Who's inputting that data and maintaining that database? So there have been some questions that have come up. We convened an industry panel around this issue and related issues a few months ago. They were interested in looking into whether or not there are things like RFID tag technology or other sorts of automated inventory systems. Those are kind of beyond my scope and the things that I work on, but that's kind of where our thought process is headed towards. How to automate some of that data capture and turning that into a searchable database. Out here we have Menards, it's like Home Depot. People have just gotten into this idea, at least on the consumer side, that you can just go to the Menards website and search up something and see how many are in stock and what the price is. On the contractor side the issue has been they tend to have the suppliers that they typically go with and if those suppliers don't have the material, it's really difficult to make the case that they should be looking at alternate suppliers of a similar material but of a salvage store. On the commercial side, on the contractors side, what a lot of folks have been talking about here locally is more information and awareness to promote the idea of yes there are organizations that have this material available to you. You can use this material and here's how it connects back to that resource. There is a great example in Atlanta where the Kendeda Fund building at Georgia Tech was opened a couple of years ago, and they used about 25 thousand linear

feet of salvaged lumber in manufacturing NLT in that building. That lumber was made available through the film industry in Georgia. They were shutting down some film sets and that lumber was there. But it was Life Cycle Building Center, which is a large reuse organization in Atlanta, that just happened to have a board member from the general contractor that was doing the work. So he was able to connect to them because he knew of the organization and make a pretty significant impact in terms of how that building was designed and constructed. That is kind of like one model, just making sure that there is more information availability about what these sources are and how contractors can connect to them. And then the other is automating that kind of database of materials that people can more easily search out what they are looking for.

2. Gilli, I am wondering if I might call on you to give a European perspective to how that's done over there. You mentioned the material passport. Is there any effort to take building information modeling and sort of geolocate it to the building site? Or how are you doing that in Europe?

Gilli Hobbs: I wouldn't suggest that it's mainstream but there's definitely things happening now. I talked about pre-demolition audits and the urban mining. If we are looking at the existing built environment as the material bank currently, then it's really understanding what's there and how it can be extracted in a way that means it can be reused for example. Then assigning property information that says maybe you can extract it intact, but has it got sufficient life cycle left to be able to reuse again in the same application. There are all these sorts of bits of information that you need to have at your disposal to make those decisions. I think this is where the link to things like building information modeling and digitalization of data is really important. We have got a few projects and activities where we sort of start, we call it creating a digital twin, to facilitate deconstruction to do BIM retrospectively on an existing building. We just started doing this in research projects and now there are service providers that will go and do this. They will do things like cloud point scanning and photogrammetry. From that you can start to get a really good interpretation of the existing asset and then you create data layers. Some of those data layers could be the sort of data or the attributes that are captured within a material passport. Which is basically what is it, what is the quality of it, what are the potential reuse options. By creating this material passport enables you to link into the systems that are starting to be created. We have one in the Netherlands called the Excess Material Exchange. You can automatically put that product from the digital twin into a materials exchange that makes it available for reincorporation into other projects. The whole idea of donor versus beneficiary you have to capture the information on the donor side to enable the beneficiary projects to first of all know that they are there. This is the whole idea that someone that was there just happened to make that link.

We need to make it an automatic process where the data captured the right way is put into a publicly accessible system so that those organizations and those designers that are actively looking to replace new with reclaimed can find that inventory of parts of materials very quickly. I think this is where the planning process is critical because we require that to happen is part of the planning process say we'll give you permission to do deconstruction of this asset, but you have to then put that information onto a publicly available excess materials exchange type thing. That then becomes available to designers. You put it in sufficiently up front so that it can then be incorporated into the design process. It is then a question of how to incentivize that from the new development perspective. Things like caps on embodied carbon can be a very effective way of saying I can't put what I normally put there since it will make me exceed my embodied carbon per meters squared threshold

that is now mandatory. So, I have to now look for things that have got a very low embodied carbon. I think as Jordan pointed out, reuse and reclaim parts of materials to have a very low embodied carbon so they then become part of the solution. It is the linking of all this stuff up and making it very easy to access and standardize in the data that enables that sort of linking across from its here to you can use it there and the drivers that actually push that into a reality.

3. There has been a lot of discussion about cost. How do these different pathways that you described George and Gilli effect cost? Have you studied a comparison of the carbon cost and labor impacts of reclaimed mass timber as opposed from creating mass timber from virgin timber?

George Berghorn: Let me take the second question first because when we did our study on that reclaimed wood glulam and CLT we were capturing a large amount of data that relates to that question. We've not analyzed it yet but we have the data in place, particularly as it relates to one of the bigger concerns that came up. It was how much you lose, in terms of saw dust, from cutting and prepping that salvaged wood to make it acceptable for use in manufacturing that glulam and CLT. It's a significant amount because one of the issues that you run into is everything has to be straight edged. With a lot of the salvaged material that comes in its got some warps, some canting on at least of edge. There's a lot of loss due to straight lining in that wood. Then in order to meet manufacturing standards you have to plane the faces that are going to receive resin. There has to be a certain amount of material planed off within a certain amount of time from the resin being applied, whether it's new material or reclaimed. One of our questions that came up for a future project is with salvaged wood, sort of the nature of it, could we get some of that same adhesive adhesion performance without planning to a fresh surface but instead taking advantage of the added surface area that exists on a lot of that product. As you know wood as wood seasons the grain raises, so you end up with a product that has more surface area in its condition as you extract it. So that is again a future question. I'm hoping within the next six months to a year we will publish what we learned about some of the carbon and cost impacts of manufacturing those products at least within the lab setting. Going back to the first question, cost continues to be an issue primarily because of the higher labor cost that's involved with deconstruction. There's really just no two ways about it. Deconstruction is just a more labor-intensive process. With the way may contracts are written currently in the Midwest is that the contractor can become the owner of the salvaged material. If you net it out, the idea is that your net costs are going to be reduced by capturing that material and then selling it or reusing it in another project. We haven't really seen that play out very well in Michigan and the Midwest because of the lack of maturity of market. There's some work, we started a little of this work. We've got some private individuals who are going to be getting into this work a little more. We've looked as some possibly robotic applications to speed the processing of lumbar once it's been removed from a structure to try to cut down on some of those costs at getting at the material. We have not seen much at our scale that's been very favorable in terms of the cost comparison to actually do the deconstruction versus how cheaply you can do demo. Our other problem in Michigan is we have the lowest land filling rates in the Midwest, so there is very little incentive at least from a financial perspective to minimize waste that is going off of the site. Prices are just so cheap in Michigan right now.

4. So Kent Duffy put in the chat old wood can be much stronger in part because it is drier. Is there a potential for it to be recognized for greater strength as a benefit? That also tied to someone else's question about the grading process for this. Could you speak to that a little bit George?

George Berghorn: So we just matched machine grade requirements for soft wood lumber. We initially did visual grading just to kind of how the visual grade compares to virgin material, but then we ended up doing MSR, machine stress rated, lumber on all of it. Again, the MOE values, the modulus of elasticity values, are very favorable with salvaged material versus virgin. Modulus of rupture is also very favorable, so stress and strain values are good for this material. Density of material is also excellent. What we saw in our samples was some higher density in a given species in the salvaged versus the virgin. Of course another advantage right now is we tend to harvest for virgin softwood lumber compared to what was harvested 70-80 years ago the quality difference in the virgin material is much different. One question that's been asked of us is, okay so what happens 60 years from now when we are trying to deconstruct current homes that we made with lumber that we didn't think was all that great when it was new and installed in the first place? I think that's a fair question that needs to be thought about going forward. I mean if anyone has bought lumber in the last five years, the stuff that you get is just not great. There is not good material out there. What's going to happen when that's sat under load for 60 years? I don't know.

5. You are talking about moving lumber from residential housing to CLT or glulam, but could you talk about what you do with that glulam or CLT at the end of a mass timber building's life or ways that we as designers can think about how to improve the use of that initially through the design process? This is for all of you but George maybe wants to start.

George Berghorn: That's the \$64,000 question right now. One of the things we've not done much work with, and we as the collective we, are the end of life options particularly for CLT because at least in the US it is such a new material for us. I have a colleague at MSU who is doing work on biobased resins for manufacturing CLT and glulam. Part of her interest in doing that is those resins may represent a better option at end of life for composting or other uses like that if the material needs to be broken down physically. I think one of the best promise areas we have for CLT and glulam is thinking about how those structural members can again be catalogued and banked and then reused as structural members in the future. Forest Products Lab rebuilt their lab in Madison I think ten years ago, they had glulam roof trusses in that building from the 1930s. They found, with the exception of one truss with moisture issues, the glulam's themselves had very little deflection after sitting under a load for that period of time. The reports were that the structural nature of the material was such that it probably could have been extracted and used as it was.

Jordan Palmeri: The future reuse of CLT is interesting and how we can plan for it today. A couple things come to mind. Number one are these concrete topping slabs that we have to put on the top of all these CLT panels. I know UO and Mark's team are doing work on how to effectively get rid of these concrete topping slabs, use other materials, not use them at all. We would get benefits two-fold from that. One immediately by reducing the amount of concrete we are using today on projects and two in the future by keeping this material exposed, cleaner, it is no longer a composite material. I think that would be one thing that would be great. I know there is more work. I am probably less familiar than others on all the CLT work, but I know fireproofing is a big issue. So how we can address fireproofing? Again, how can we strip this material down to its bare bones, keep it exposed, keep it beautiful, keep it as reusable as possible. I think one thing we can learn from other structural members that we see for reuse is just labeling. Stamping and labeling in multiple places along an structural member so that 40, 50, 60 years down the road we know what we

are looking at when we are taking that building apart. Maybe we won't figure out this whole data base of material banks and instead we will just have to look at the material in an old fashion kind of way. So, I think stamping and labeling will be important. Finally, I will just give one more pitch for use the whole tree. When we think about circularity, I don't think we are going to be seeing CLT slabs coming out of buildings for hopefully 60 plus years. When we are looking that far down the road, I think we should also be thinking about the other materials that are coming out of the mill process when we are making CLT. Thinking about any short term wood products that we can make into long term wood products would kind of help close the loop on that circularity.

6. Gilli, not to put you on the spot but you had a head start on mass timber products compared to the US, do you have any thoughts?

Gilli Hobbs: Not really specifically on timber CLT, but I suppose more generally looking at the whole cost and the future value question. I think it has been touched on already about how once you have that data and information you don't have to make a decision now. As long as you put things in a way where they can be reversed out for future reuse, then that in itself is a good principle that should be applied in irrespective that there is a future reuse in 20, 40, 60 years. I think our assets seem to either last a lot longer than we expect them to or they last a much shorter time than we plan them to. Having that ability to be adaptable, to be deconstructed, to be disassembled, unless it incurs significant cost or impact, why wouldn't you do it? It is good practice to do it. That applies to all the products and materials. I just wanted to flag some really interesting developments, again in the Netherlands tend to be a bit further ahead than the rest of us with these things. This sort of takes the concept of building material banks to the next level which is we are starting to get companies that are developing an idea of buying the urban mining rights. So the value of products and materials within buildings, they are not going to be demolished and we don't know when they are going to be demolished, but they are sort of going around and buying up those rights now. If you do it across thousands of buildings essentially you will get this continuum of products and materials that you then have ownership rights to as those buildings are stripped out or deconstructed in the future. I think that's going to be a really interesting development because at the moment we don't really have a good understanding of what the residual value of CLT or a piece of timber or bricks.

What is the actual value? I think as soon as we start to get into that mainstreaming of we are going to buy the rights to that people will automatically want to assign a value to it. That value will be linked to what's the future likely reuse potential at what level and application. I think once that starts we will actually see an economic metric that helps us understand well okay we are putting these products and materials today, well they are not going to be worth much in 60 years' time because the market isn't paying much for them. Or maybe they will be worth a lot more because they have been designed to be demountable and reusable. That will hopefully start to tip the balance a little bit toward actively having products, materials, systems that are repairable and upgradable because they retain their value. Just a final point, this frustrated me like nothing else, part of the building materials bank project was just trying to understand that life cycle costing that is standard is all done a certain way and if you do a building in a circular way it makes absolutely no difference to the life cycle costing evaluation. Because the way in which they do that, everything is depreciated to zero. So even if you create these whole systems whereby you try to have this residual value at end of life, the current way in which we cost and value buildings makes that impossible to recognize within the current norm. Those are the sorts of things we need to

change because if you can't show that when you are trying to put that asset in on day one, how on earth are you going to convince people to make these changes. They don't sound like an awful lot but bringing these things together, getting the costing modeling that reflects reality better, understanding residual value, being able to have the data that we know what stuff is worth and we are able to assign information to it in a virtual sense, but also things like tagging will give you confidence that you are not going to lose that information. These are all part of the things that have to change to make this a reality.

7. Gilli, I am going to follow up with another question for you. Going back to material passports again, is there a centralized group that's working to standardize these and how could designers further the effort? In addition to the benefits for circular design the standard product ID would help designers who are already specifying based on other factors like embodied carbon, materials toxicity, and equity. Right now these efforts seem to be largely dispirit so there's no way to quickly understand which declarations that are associated with the same product without going to each individual manufacturers website. So curious if you have any thoughts on that.

Gilli Hobbs: I completely agree it's all over the place. So having a standard for circularity information on products with product passports or product data templates is really critical, but getting that consensus is not easy. There's some work that has been carried out in Luxembourg called the Product Circularity Data Template I think it is. In Luxembourg they tried to standardize what we would call a material passport. They are trying to standardize the data fields that should be captured within that circularity data sheet. So that's a really important piece of work. One of the standards that you read out, the European Standard for Circularity within the Built Environment Construction Sector, is they will be developing European standards in a whole number of areas and we are expecting that one of those areas will be a product data template or passport. That would then enable rather than manufacturers providing the same information slightly different ways, at least we can then actually standardize that. Actually, the revision of the construction products regulation would actually make that mandate real across the EU. So that's why it's such an important piece of legislation in terms of if were to revise that and say from now on, in terms of declaration performance, you have to include these bits of information on aspects that are important in circularity for example. That then means that all manufacturers would have to legally provide that information and they would legally have to write that information in the way that it's prescribed under the standard metric. That then cuts out a lot of this ad hoc approach to providing that information.

8. Terrific, so Jordan I want to turn back to you to get into the weeds just a little bit. There is a question that reads, when you say that we should use a 20 year GWP, how do you account for that in your calculations? Do you assume annual GWPs for green house gas emissions and then multiply by 20, curious about your actual process for accounting.

Jordan Palmeri: This is just standard LCA accounting of global warming potentials. So each pollutant has what is called a Climate Forcing Potential, it is essentially how much heat is trapped in the atmosphere by that gas. These gases have a lifespan, like methane is a shorter lived pollutant than carbon dioxide. Eventually methane will actually degrade in the atmosphere and will no longer be trapping heat, but it's a very strong climate pollutant in the short term. Each gas has different heat trapping potentials on different time scales. So if we are only counting how much heat trapping potential happens within 20 years, different materials are going to show up at different levels. If you go

to the EPA Tracing Method online, you can look a little bit more at GWP 20 versus GWP 100. I think I will stop there for this type of forum and getting into the weeds a little too deeply there.

9. I'm going to stay in the vein of LCA here, and this is for all panelists. Thinking about when we perform a whole building LCA and benchmark a building using software that's available out there, often when you account for biogenic carbon at building end of life there are assumptions made to think that many years down the road. The assumptions can range and vary between software and even between the assumptions made for that ultimate carbon calculation. How should we feel comfortable with those assumptions and are there ways to investigate the assumptions to feel more or less comfortable with the number that we are getting?

Jordan Palmeri: I'll take a shot at that Mark. For the Tally software they publish and are transparent about what their end-of-life assumptions are. What their split is between landfilling and recovering and burning for energy. If you are in Oregon and want to figure out how accurate that is, you could go and use our tool here and say how is Tally treating the wood versus how it actually gets recovered and/or disposed in Oregon. You could do a quick comparison. We have not done that yet. Our job is just to model what is actually happening in Oregon. I encourage people to do that. That's one way to do a gut check of how well the software is taking these things into account. I think that would be the first step.

10. George, going back do you have any engineers from SE2050 involved in the study you mentioned at the beginning of your presentation?

George Berghorn: Engineers yes, specifically from SE2050 no. If the person that asked that question has some connection to SE2050 group that is something I would be interested in exploring offline.

11. Jordan, Oregon produces about 11% of the worlds lumber, presumably most leaves the state, how does that correlate to what is used in state? If you have a follow up on that go ahead. I was looking at my other screen.

Jordan Palmeri: One the last question on end of life, software, and waste, I just wanted to make one more point and then I'll address the other one. I really want to emphasize that when we do life cycle assessments we should be interpreting the results as directional guidance. LCAs don't give us the answer, it's not like the magic ticket. LCAs should be used as directional guidance. One thing about using LCAs and end of life, especially when you are constructing a building today and modeling something in Tally, is we are hoping that the end of life for that building is a good 60, 80, maybe 100 years away. We don't know what the material recovery system is going to look like 60, 80, 100 years from now. We've only had a material recovery system in Oregon since like 1990 and already it has rapidly changed. Just take that into account as you're looking into these end of life scenarios and remind ourselves that we don't have 80 years to deal with climate change. We have more like twenty. That is a lot of the reason why we are looking so heavily at A1 through A3 production related impacts. That's my piece on LCA as directional guidance. I think the question was about wood and production versus consumption. Yeah, there is a really stark difference between my chart where I showed how much wood is being produced in Oregon and how much we have in the waste stream and the chart that George showed where he said we are harvesting just as much wood as we are disposing of. We are looking at two different scales. In Oregon, we are in a timber state. Yes, these scales are vastly different. I don't know the percentage of the wood that goes out of state off the top of my head, but it's a

considerable amount. The study that Oregon Department of Forestry did, they weren't just looking at the wood in Oregon. They were looking at the wood harvested in Oregon and goes elsewhere and what are the fates of carbon in those different wood products. They found that a lot of this material goes into short lived products that don't last very long. That is the thread I was going on for shifting from short lived to long lived. I do think it's important when we are living in a timber state and we are physically located near these resources that we are aware of what is flowing around us. If we are designers and engineers and architects start demanding other products, like some of these insulation products I was talking about, we might see a shift in local production. Since I worked for the states environmental agency, I care both about what we are producing, because these are the industries that we are regulating at the state, and that which we are consuming. The stuff that we are producing goes all over the place and the stuff that we are consuming comes from all over the place. We really do need to have a global view of this because carbon emissions are a global problem. They don't follow neat little boundaries.

12. I think that's a terrific summary. I am cognizant of time here. We are close to the end of our Q&A. I think what I would like to do is see if the panelists have any other final thoughts on before we wrap up.

Gilli Hobbs: Just a quick follow up on the LCA side of things. I actually think we need to be looking at more than one asset life cycle. As part of the Band project we looked at three life cycles: the existing so what is already there, the current so the thing you are designing, and then the future, to try to get the best balance across these three life cycles. I think we need to overlay this idea that we need to reduce carbon emissions now. I totally agree with Jordan that it means we need to focus on reducing the current A module. That therefore means we need to retain assets that are already here as much as possible within reason. If we can't retain those assets, can we retain the products in the materials and reuse those. That then displaces new products and materials that will have this embodied carbon associated with it. What's quite interesting in France is they are developing this whole idea of dynamic LCA modeling to get to grips with the carbon expended now versus future carbon, because we know we have got to do something as soon as possible. They have also got to grips with instead of agonizing over what is the embodied carbon impacts of reuse, they have just allocated an impact of zero. Therefore, if you reuse everything, its got an embodied carbon of zero versus whatever the new alternative is going to be. These are quite simple pragmatic things that are happening in the world of LCA in France and probably in other places. I like to realize the idea that LCA is directional guidance and if we focus on it too much then we really do miss the big picture of trying to make the best decisions that we can now and focus on the issues of today, rather than thinking about what is going to be the carbon impacts in or 80 years' time. We just don't really have that luxury to be honest.

Jordan Palmeri: Gilli that was really interesting. I am very interested to look into that France example there. End of life and recovery of materials is really important. In Oregon we're doing really well already, and I would encourage the rest of our recycling and recovery efforts to move more towards a product stewardship approach. I think material manufactures need to take more responsibility for their products and end of life. I hope that we see more of that in the construction sector. I also hope that it will free up more of your time on the call, everyone in the AEC community, to focus more on reuse. We've hit it over and over again today that reuse is really key. We definitely have not cracked that nut, in that it is difficult. There were a few comments there about how we encourage reuse, how do we specify reused materials. We need more

demand. We see materials suppliers closing down here in Portland despite our great deconstruction market because there's just not as much demand for these salvaged materials. We really need to see more demand. I would also really encourage you to share success stories and training opportunities for how to do this. How do successfully reuse materials and create more of a circular economy. I was inspired by Gilli's example of what they are doing in the Netherlands where on government procurement contracts they are actually training the contractors and other types of people how to do this kind of work. We do really need to work more as a community to come up to speed here, so thanks Mark.

George Berghorn: Echoing on Jordan talking about extending life cycles, we didn't talk much about adaptive reuse but that's something as a community that we should also be thinking more about and working towards in a more holistic way. We watched in sort of a rapt fascination as an apartment building was built right across the street from my office at MSU. You probably know this but at MSU there is this move towards luxury student housing. The student housing has ratcheted up a lot probably since most of us were ever in college. The developer for this project, and understandably so, wanted to build it as quickly as they could. Thirteen story apartment building, they put up a story every eleven days. The way they did it was with load bearing light gage steel structure throughout the building. So they built a luxury student apartment building that can never be anything other than a luxury student apartment building. Every wall in the structure is loadbearing. Almost every wall in the building has a fire separation attachment to it. So if student preferences changed in another 15 years, thinking back to where they were 15 years ago, that building becomes a relic. I think we need to start further upstream, work with developers, work with building owners. To do more education in that space around the adaptability in buildings and making some of these wise material choices to deal with that sort of A1 to A3 as well as new construction is being put in.

End of Discussion